

CHAPTER 15

MATERIALS TESTING: SOIL AND CONCRETE

In previous chapters of this TRAMAN, you studied the importance of many and various construction materials. However, one material that was not discussed was SOIL which, as you will learn in this chapter, is perhaps the most important material of all. Just as a poorly constructed and weak concrete foundation will not support a building, neither will a poorly “constructed” and weak soil, since the ultimate foundation for any road, airfield, building, or other structure is the natural earth upon which it is built.

During this chapter you will learn what soil is. You will learn the different types of soil you might encounter. You will also learn the basic properties and characteristics of soil and the importance those characteristics play in determining the adequacy of a soil for use as a construction material. In addition, you will learn how to collect (sample) soil for testing purposes and how to perform certain tests that you, as an EA3, will be responsible for performing. Most importantly, you will learn why those tests are performed and their importance in properly and correctly identifying and classifying the many types of soil that exist in nature.

Finally, this chapter begins your studies of concrete testing. In this chapter you will learn what the various tests are and the purpose and importance of those tests. You will learn how to perform certain tests and how to prepare concrete samples for other tests that will be performed by more senior EAs.

SOIL ORIGIN

As defined by Webster's New World Dictionary, *soil* is the surface layer of the Earth that supports plant life. While that is certainly a correct definition and one that is perfectly satisfactory to many groups of people, it lacks the precision required by the civil engineer and soil technician. A more precise definition is that soil is a mixture of uncemented or loosely cemented

mineral grains enclosing various sizes of voids that contain air (or other gases), water, organic matter, or different combinations of these materials in varying amounts. The importance of understanding this definition will become obvious as you progress through this chapter; but, first, let us consider where soil comes from.

SOIL FORMATION

The formation of soil is a continuous process that is still in action today. Basically, the Earth's crust consists of rock, which geologists classify into three groups: igneous, which is formed by cooling from a molten state; sedimentary, formed by the accumulation and cementing of existing particles and remains of plants and animals; and metamorphic, formed from existing rocks that have been subjected to heat and pressure. When exposed to the atmosphere, this rock undergoes a physical and chemical process called WEATHERING, which, over a sufficient length of time, disintegrates and decomposes the rock into a loose, incoherent mixture of gravel, sand, and finer material. It is this process that produces soils of various designations.

RESIDUAL SOIL

Any soil that results from weathering in place, and that is not moved during the weathering process, is called a RESIDUAL soil. A mantle of residual soil reflects the characteristics of the underlying parent rock from which it was derived.

TRANSPORTED SOIL

When the forces of nature cause the mantle of soil to be moved to a place other than that of its origin, the soil becomes a TRANSPORTED soil. One of these soils often bears properties induced by its mode of transportation. The chief agents of transportation are water, wind, ice, and the force of gravity.

Alluvial Soil

ALLUVIAL soil is formed when a soil-carrying stream gradually loses its carrying capacity with decreasing velocity. In slowing down, a river does not have sufficient power to keep the large particles of soil suspended; these particles settle to the riverbed. Further decrease in velocity causes smaller particles to settle. As the river becomes slow and sluggish (as in the lowlands where its gradient becomes small), it holds only the extremely fine particles in suspension. These particles are deposited, finally, at the mouth of the river, where they form DELTAS of fine-grained soil.

Marine Soil

MARINE soil is formed from materials carried into the seas by streams and by material eroded from the beaches by the tidal action of the waves. Part of the material is carried out and deposited in deep water; part is heaped upon the beaches along the coast.

Lacustrine Soil

Freshwater lake deposits are called LACUSTRINE soils. Generally speaking, they are fine-grained soils resulting from material brought into freshwater lakes by streams or rivers.

Aeolian Soil

Wind-transported grains make up AEOLIAN soils. Sand deposits from wind are called "dunes," and the finer particles (which are generally carried further) are deposited to form a material called LOESS. Dune deposits seldom contain material larger than sand size.

Glacial Soil

GLACIAL soil is often called DRIFT. It consists of material carried along with or upon an advancing ice sheet or of material pushed ahead of it. As glaciers melt, deposits of various forms occur, such as MORAINES, KAME TERRACES, ESKERS, and OUTWASH PLANES. Moraines consist of mixtures of unstratified boulders, gravels, sands, and clays. The other forms (kame terraces, eskers, and outwash planes) mentioned consist of somewhat stratified and partly sorted stream gravels, sand, and fines transported outward from the glacier by streams during the melting period.

Colluvial Soil

COLLUVIAL soil consists of mixed deposits of rock fragments and soil materials accumulated at the bases of steep slopes through the influence of gravity.

Table 15-1. Size Groups as Used in the Unified Soil Classification System

Size Groups	Sieve Size	
	Passing	Retained on
Cobbles -----	No maximum size* -----	3 in.
Gravels -----	3 in. -----	No. 4
Sands -----	No. 4-----	No. 200
Fines -----	No. 200-----	No minimum size

*In military engineering, maximum size of cobbles is accepted as 40 inches, based upon maximum jaw opening of the crushing unit.

PHYSICAL CHARACTERISTICS OF SOILS

The physical characteristics of soils aid in determining their engineering characteristics and are the basis of the system of soil classification used in the SEABEES and by the military in general for the identification of soil types. A knowledge of these physical characteristics aids in determining the degree to which local soils can be used in engineering projects to support traffic loads or to serve as a subgrade or foundation material. Those characteristics of concern to the EA are discussed below.

PARTICLE SIZE

Soils are divided into groups based on the size of the particle grains in the soil mass. The EA identifies the sizes through the use of sieves. A sieve is a screen attached across the end of a shallow cylindrical frame. The screen permits particles smaller than the openings to fall through and larger ones to be retained on the sieve. When sieves of different sizes are stacked so that the largest screen openings are at the top and the smallest at the bottom, soil can be separated into particle groups based on size. The amount remaining on each sieve is measured and described as a percentage by weight of the entire sample. Table 15-1 shows size groups as used in the Unified Soil Classification System. Particles passing the No. 200 sieve but larger than 0.002 mm to 0.005 mm are called silt, and those finer are clays.

PARTICLE SHAPE

The shape of the particles influences the strength and stability of a soil. Two general shapes are normally recognized: BULKY (fig. 15- 1) and PLATY.

Bulky

Cobbles, gravel, sand, and silt particles cover a large range of sizes; however, they are all bulky in shape. The term bulky is confined to particles that are relatively large in all three dimensions, as contrasted to platy particles, in which one dimension is small as compared to the other two. The bulky shape has the following four subdivisions listed in descending order of desirability for construction:

ANGULAR particles are those that have been recently broken up and are characterized by

jagged projections, sharp ridges, and flat surfaces. Angular gravels and sands are generally the best materials for construction because of their interlocking characteristics. Such particles are seldom found in nature, however, because the weathering process does not generally produce them. Angular material must usually be produced artificially, by crushing.

SUBANGULAR particles are those that have been weathered to the extent that the sharper points and ridges have been worn off.

SUBROUNDED particles are those that have been weathered to a further degree than subangular particles. They are still somewhat irregular in shape but have no sharp corners and few flat areas. Materials with this shape are frequently found in stream beds. If composed of hard, durable particles, subrounded material is adequate for most construction needs.

ROUNDED particles are those on which all projections have been removed, with few irregularities in shape remaining. The particles resemble spheres and are of varying sizes. Rounded particles are usually found in or near stream beds or beaches.

Platy

Platy (or flaky) particles are those that have flat, platelike grains. Clay is a common example. Because of their shape, these flaky particles have a greater contact area for moisture and are undesirable for construction purposes.

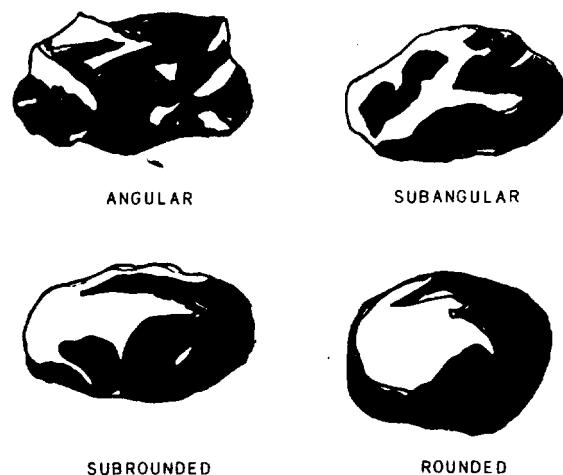


Figure 15-1. Types of bulky-shaped soil particles (grains).

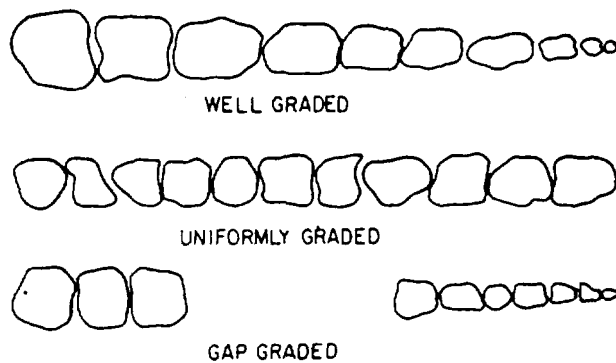


Figure 15-2.-Types of soil gradation.

GRADATION

The size and shape of the soil particles discussed above deal with properties of the individual grains in a soil mass. Gradation describes the distribution of the different size groups within a soil sample. The soil may be well or poorly graded.

To be classified as WELL GRADED, a soil must have a good range of all representative particle sizes between the largest and the smallest. All sizes must be represented, and no one size should be either overabundant or missing (fig. 15-2).

Poorly graded soils are either those containing a narrow range of particle sizes or those with some intermediate sizes lacking (fig. 15-2). Soils with a limited range of particle sizes are called UNIFORMLY GRADED. Soils that have some intermediate size or sizes not well represented or missing are called GAP GRADED, STEP GRADED, or SKIP GRADED.

COMPACTNESS

Compactness refers to how closely a mass of soil particles are packed together; the closer the packing, the greater the compactness and the larger the weight of soil per unit volume.

The structure of a total mass of soil particles may be dense. In this case, the particles are closely packed and have a high degree of compactness. A dense structure provides interlocking of particles with smaller grains filling the voids between the larger particles. When each particle is closely surrounded by other particles, the grain-to-grain contacts are increased. This lessens the tendency for displacement of the individual grains

under load, and the soil is then capable of supporting heavier loads. Well-graded coarse materials usually are dense and have strength and stability under load.

On the other hand, the structure may be loose, in which case the particles are not packed as closely together as possible, thereby lacking compactness. Loose, open structures have large voids, which will lead to settlement or disintegration when foundation or traffic loads are applied.

SPECIFIC GRAVITY

Specific gravity is designated by the symbol G_s . It is defined as the ratio between the weight per unit volume of the material and the weight per unit volume of water at a stated temperature—usually 20°C. If you use the system international (SI) (metric) system, you can determine specific gravity by the following formula:

$$\text{Specific gravity} = \frac{\text{weight of sample in air (g)}}{\text{weight of sample in air (g)} - \text{weight of sample submerged (g)}}$$

Test procedures will be discussed in detail later in this chapter. The specific gravity of the solid substance of most inorganic soils varies between 2.60 and 2.80. Tropical iron-rich laterite, as well as some lateritic soils, generally has a specific gravity of 3.0 or more. Sand particles composed of quartz have a specific gravity of about 2.65. Clays can have values as high as 3.50. The solids of soil particles are composed of minerals. Generally, these minerals have a specific gravity greater than 2.60. Values of specific gravity smaller than that are an indication of the possible presence of organic matter.

SOIL MOISTURE

The moisture content of a soil mass is often the most important factor affecting the engineering characteristics of the soil. The water may enter from the surface or may move through the sub-surface layers by either gravitational pull, capillary action, or absorption. This moisture is present in most cases. It influences various soils differently; it probably has the greatest effect upon the behavior of the soil when the soil is subjected to loading.

Sources of Water in Soils

Surface water results from precipitation or runoff and enters the soil through the openings between the particles. This moisture may adhere to the different particles, or it may penetrate the soil to some lower layer.

Subsurface water is collected or held in pools or layers beneath the surface by a restricting layer of soil or rock. This water is constantly acted upon by one or more external forces.

Water controlled by gravity (free or gravitational water) seeks a lower layer and moves through the voids or spaces until it reaches some restriction. This restriction may be a bedrock or an impervious layer of soil whose openings or voids are so small as to prevent water passage.

The voids or spaces in a soil may form continuous tunnels or tubes and cause the water to rise in the tubes by capillary action (capillary moisture). The smaller the tube, the stronger the capillary action; therefore, the water rises higher in the finer soils, which have smaller interconnected voids. This area of moisture above the free water layer or pool is called the capillary fringe.

Another force acting on soil water is absorption by the atmosphere. As the moisture evaporates from the soil surface, more moisture is drawn from the soil below and is, in turn, also evaporated. This process continues until the soil is in an airdry condition in which the moisture in the soil is in equilibrium with the moisture vapor in the air. In this airdry state, the moisture remaining in the soil is in the form of thin films of water surrounding the individual soil particles and is called the hygroscopic moisture. These moisture films are due to naturally occurring electrical forces, which bind the water molecules to the soil particles. Hygroscopic moisture films may be driven off from airdried soil by heating the material in an oven at a controlled temperature for 24 hr or until constant weight is attained.

To define the amount of water present in a soil sample, the term *moisture content* (symbol w) is used. It is the proportion of the weight of water to the weight of the solid mineral grains (weight of dry soil) expressed as a percentage or

$$w = \frac{\text{weight of water}}{\text{weight of dry soil}} \times 100$$

When wet soil is dried in air in the laboratory, the amount of hygroscopic moisture remaining in the airdried soil, expressed as a percentage of the weight of the dry soil, is called the hygroscopic moisture content.

Plasticity

Plasticity is a property of the fine-grained portion of a soil that allows it to be deformed beyond the point of recovery without cracking or changing volume appreciably. Some minerals, such as quartz powder, cannot be made plastic no matter how fine the particles or how much water is added. All clay minerals, on the other hand, are plastic and can be rolled into thin threads at a certain moisture content without crumbling. Since practically all fine-grained soils contain some clay, most of them are plastic. The degree of plasticity is a general index to the clay content of a soil.

The term *fat* and *lean* are sometimes used to distinguish between highly plastic and slightly plastic soils. For example, lean clay is only slightly plastic, whereas fat clay is highly plastic. In engineering practice, soil plasticity is determined by observing the different physical states that a plastic soil passes through as the moisture conditions change. The boundaries between the different states, as described by the moisture content at the time of change, are called consistency limits or Atterberg limits.

The liquid limit (LL) is the moisture content corresponding to the arbitrary limit between the liquid and plastic states of consistency of a soil. Above this value, the soil is presumed to be a liquid and behaves as such by flowing freely under its own weight. Below this value, it deforms under pressure without crumbling, provided the soil exhibits a plastic state.

The plastic limit (PL) is the moisture content at an arbitrary limit between the plastic and semisolid state. It is reached when the soil is no longer pliable and crumbles under pressure. Between the liquid and plastic limits is the plastic range. The numerical difference in moisture content between the two limits is called the plasticity index (PI). The equation is $PI = LL - PL$. It defines the range of moisture content within which the soil is in a plastic state.

The shrinkage limit is the boundary in moisture content between the solid and the semisolid states. The solid state is reached when the soil sample, upon being dried, finally reaches a limiting or minimum volume. Beyond this point, further drying does not reduce the volume but may cause cracking. The limit tests are described later in this chapter.

Effects of Soil Moisture

Moisture affects coarse-grained soils much less than fine-grained soils. One reason for this is that

coarser soils have larger void openings, and, as a rule, drain more rapidly. Capillarity is practically nonexistent in gravels and in sands containing little fines. These soils, if they are above the groundwater table, will not usually retain large amounts of water. A second reason is that since the particles in gravelly and sandy soils are relatively large (in comparison to clay and silt particles), they are, by weight, heavy in comparison to the films of moisture that might surround them.

On the other hand, the small (sometimes microscopic) particles of fine-grained soil weigh so little that water in the voids has considerable effect. It is not unusual, for example, for clays to undergo large volume changes with variations in moisture content, as witness the shrinkage cracks in a dry lake bed. Consequently, unpaved clay roads, though hard enough when sun-baked, often lose stability and turn into mud in rainy weather.

Not only do clays swell and lose stability when they become wet, but they also, because of their flat, platelike grain shapes and small size, retard the drainage of water. Since drainage is of the greatest importance in (for example) the construction of airfield pavement, design engineers must know whether or not subsurface clay exists. Plasticity is, as you know, the characteristic by which clay is primarily identified.

ORGANIC SOILS

Soils of organic origin are formed either by the growth and subsequent decay of plant life or by the accumulation of inorganic particles of skeletons or shells of organisms. The term *organic soil*, though, refers to soils containing mineral grains and a more or less conspicuous admixture of vegetable matter. An organic soil may be an organic silt or clay, or it may be a HIGHLY ORGANIC soil, such as peat or meadow mat.

Organic soils are most often black in color, and usually have a characteristic musty odor. These soils are usually compressible and have poor load-maintaining properties.

EFFECTS OF SOIL CHARACTERISTICS

In summary, soil characteristics are a measure of the suitability of the soil to serve some intended purpose. Generally, a dense, solid soil withstands greater applied loads (has greater bearing capacity) than a loose soil. Particle size has a definite relation to this capacity. From empirical

tests, it has been found that well-graded, coarse-grained soils generally can be compacted to a greater density than fine-grained soils. This is because the smaller particles tend to fill the spaces between the larger ones. The shape of the grains also affects the bearing capacity. Angular particles tend to interlock, form a denser mass, and become more stable than the rounded particles, which can roll or slide past one another. Poorly graded soils, with their lack of one or more sizes, leave more or greater voids and comprise a less dense mass. Moisture content and the consistency limits aid in describing the suitability of the soil. A coarse-grained sandy or gravelly soil generally has good drainage characteristics and may be used in its natural state. A fine-grained clayey soil with a high plasticity index may require considerable treatment, especially if used in a moist location.

SOIL CLASSIFICATION

As can be inferred from the previous discussions in this chapter, soil types are important factors to consider when selecting the proper location on which to construct any structure or facility. With the soil accurately identified and described, its suitability for supporting traffic as a subgrade, base, or foundation material or as an aggregate, a filler, or a binder for a mixture can be evaluated.

CLASSIFYING SOILS

The UNIFIED SOIL CLASSIFICATION SYSTEM (USCS) is a common soil classification reference or system that has a universal interpretation. In this system, all soils are divided into three major divisions as follows:

COARSE-GRAINED SOILS are those in which at least half of the material, by weight, is larger than (retained on) a No. 200 sieve. This division is further divided into GRAVELS and SANDS. If more than half of the coarse fraction, by weight, is retained on a No. 4 sieve, it is classified as a gravel. If less than half is retained on a No. 4 sieve, then it is a sand. Gravels and sands are further subdivided into additional categories dependent upon the amount and characteristics of any plastic fines the soil sample contains.

FINE-GRAINED SOILS are those in which more than half of the material, by weight, is smaller than (passes) a No. 200 sieve. The fine-grained

soils are not classified on the basis of grain size distribution but according to plasticity and compressibility.

HIGHLY ORGANIC SOILS are those organic soils, such as peat, that have too many undesirable characteristics from the standpoint of their behavior as foundations and their use as construction materials. A special classification is reserved for these soils, and no laboratory criteria are established for them. Highly organic soils can generally be readily identified in the field by their distinctive color and odor, spongy feel, and frequently fibrous textures. Particles of leaves, grass, branches, or other fibrous vegetable matter are common components of these soils.

CLASSIFICATION TESTS

The above is by no means a thorough description of the USCS and the methods used to classify soils; nor is it intended to be. However, the results of certain tests (sieve analysis and Atterberg limits) that you will be performing as an EA3 will be used for the purpose of soil classification. The preceding discussion is presented so that you have an understanding of why you perform the tests, what the results are used for, and the importance of ensuring that your test results are correct and reliable. A full discussion of the test procedures will be presented later in this chapter. Should you desire to learn more about the USCS and soils classification, you may refer to the EA1 TRAMAN, to NAVFAC MO-330, *Materials Testing*, or to one of numerous commercial publications on soil mechanics.

SOIL SAMPLING

In the planning and execution of construction operations, it is vital to know as much information of engineering significance as possible about the subsurface conditions in the construction area. That information includes not only the location, extent, and condition of the soil layers but also the elevation of the groundwater table and bedrock; the drainage characteristics of the surface and subsurface soils; and the location of possible borrow areas from which soil and other mineral-product materials may be "borrowed" for a construction operation. Soil surveys are conducted to gather (explore) this information. These are multifaceted surveys that consist of the following: gathering soil samples; soil testing by either laboratory or field procedures, or both; soil classification; and the development of soil profiles.

In the full scope of soil surveying, your primary concern, as an EA3, is gathering soil samples and conducting certain of the laboratory soils tests. Should you desire to learn more about soil surveying, an excellent source is NAVFAC MO-330, *Materials Testing*.

SAMPLING METHODS

The gathering, or collecting, of soil samples in the field for testing is called SOIL SAMPLING. The three principal methods of sampling are the taking of samples from the surface, from already existing excavations, and from test pits and test holes. The extent and methods used will be dependent upon the time available.

The method that provides the most satisfactory results for both studying the natural soil conditions and for collecting undisturbed soil samples is the taking of samples from test pits. A test pit is an open excavation that is large enough for a person to enter. Usually, these pits are dug by hand; however, when power equipment is available, power excavation by clamshell, dragline, bulldozer, backhoe, or a power-driven earth auger can expedite the digging. Excavations below the groundwater table require the use of pneumatic caissons or the lowering of the water table. Additionally, excavations that extend to 5 ft or more in depth may require adequate shoring and bracing to prevent cave-ins, as discussed in the previous chapter. Load-bearing tests can also be performed on the soil in the bottom of the pit.

Test hole exploration, with the use of the hand auger, is the most common method of digging test holes. It is best suited to cohesive soils but can be used on cohesionless soils above the water table, provided the diameter of the individual aggregate particles is smaller than the bit clearance of the auger. Auger borings are usually used for work at shallow depths, but if pipe extensions are added, the earth auger may be used to a depth of about 30 ft in relatively soft soils. Samples obtained by this method are completely disturbed but are satisfactory for determining the soil profile, classification, moisture content, compaction capabilities, and similar soil properties.

In a hasty soil survey, which is made under expedient conditions or when time is limited, the number of test pits and test holes is kept to a minimum by the use of existing excavations for soil sampling. In a deliberate survey, where time and conditions allow a more thorough sampling operation, test holes are used extensively and are augmented by test pits, governed by the judgment of the engineering officer.

Table 15-2. Methods of Underground Exploration and Sampling

Common name of method	Materials in which used	Method of advancing the hole	Method of sampling	Value for foundation purposes
Auger boring	Cohesive soils and cohesionless soils above groundwater elevation	Augers rotated until filled with soil and then removed to surface	Samples recovered from material brought up on augers	Satisfactory for highway exploration at shallow depths
Well drilling	All soils, rock, and boulders	Churn drilling with power machine	Bailed sample of churned material or clay socket	Clay socket samples are dry samples Bailed samples are valueless
Rotary drilling	All soils, rock, and boulders	Rotating bits operating in a heavy circulating liquid	Samples recovered from circulating liquid	Samples are of no value
Test pits	All soils. Lowering of groundwater may be necessary	Hand digging or power excavation	Samples taken by hand from original position in ground	Materials can be inspected in natural condition and place

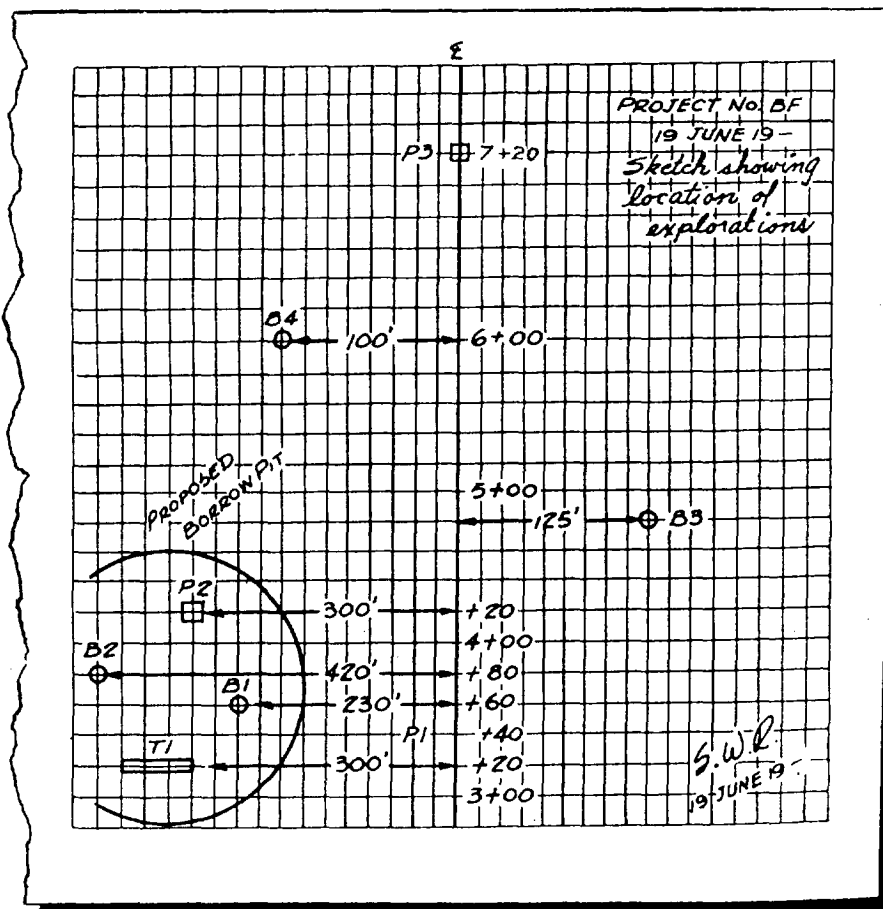


Figure 15-3. Sketch showing locations of soil exploration points.

Table 15-2 shows methods of underground exploration and sampling in a condensed form.

TAGGING SAMPLES

Let us suppose that soil in a given area is to be tested (such as the area on which a structure is to be erected). The officer in charge of soil exploration decides how many points are needed and where they must be located to produce a representative test of the soil in the area. This information is recorded in a sketch like the one shown in figure 15-3.

This figure shows the locations of exploratory points along a highway, the point locations referenced by the center-line station and the distance from the center line. To the left of the center line, between stations 2 + 80 and 4 + 60, there is a borrow pit, from which soil for fill is taken. The soil here is tested by samples taken from a 60-ft trench (T1), located at station 3 + 20, 300 ft from the highway center line; from two borings (B1 and B2) at stations 3 + 60 and 3 + 80, 230 ft and 420 ft from the center line, respectively; and from a 20-ft-square pit (P2) at station 4 + 20, 300 ft from the center line.

Besides the borrow pit exploration, there is a boring (B3) at station 4 + 80, 125 ft to the right of the center line; another boring (B4) at station 6 + 00, 100 ft to the left of the center line; and a 20-ft-square pit (P3) on the center line at station 7 + 20.

Each sample taken is tagged according to the location from which it was taken. Locations are given in consecutive numbers; for those shown in figure 15-3, the numbers might run from the bottom up, with T1 being No. 1; B 1, No. 2; and so on. A sample is tagged with the project symbol (the symbol for the project shown in fig. 15-3 is BF) and the location symbol (such as T1 or B1). If more than one sample is taken from the same location, you need to use additional numbers. For example, a sample taken from B2 in figure 15-3 maybe tagged "BF-B2-4, bag 1 of 6." This means "boring No. 2, location No. 4, the first of 6 bags taken from that location."

The sample identification is printed with a marking pencil or pen on two tags, one of which is placed inside the bag, and the other of which is tied on the outside. Gummed labels may be similarly used to identify samples that are placed in moisture content boxes, cylinders, or jars.

DISTURBED SAMPLES

Samples taken by hand scoops, auger borings, shovels, or any other convenient hand tool with no attempt to obtain the material in its natural state of structure or density is known as a DISTURBED sample. These samples are used for mechanical analysis, plasticity, specific gravity, frost susceptibility, compaction, and laboratory compacted CBR tests. The size of the sample taken will depend upon the tests to be performed.

Individual Samples

When taking individual samples from a pit, trench, or exposed face (fig. 15-4), first shave off loose and dried soil to obtain a fresh surface and to expose any soil variations clearly. Then take a typical sample of each type of soil or of those requiring additional investigation. When sampling in auger holes, place typical portions of the soil obtained

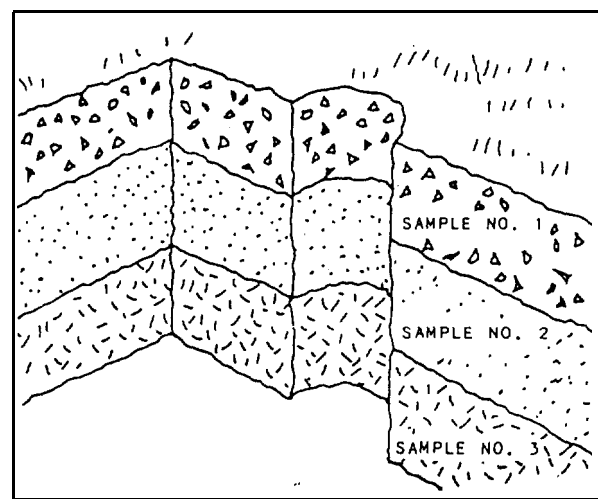


Figure 15-4.-Obtaining individual bag samples from an exposed face.

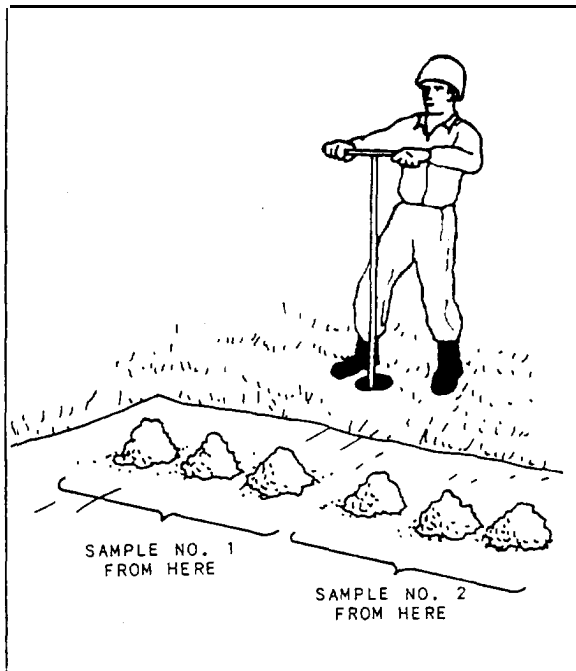


Figure 15-5.-Obtaining individual bag samples.

along a row in correct order, as shown in figure 15-5.

Composite Samples

A composite sample is a representative mixture of all soil within a soil mass to be investigated or of the material contained in a stockpile or windrow of soil excavated from a trench. A test sample is obtained from a composite sample by quartering (to be explained later) in the laboratory.

To take composite samples from test pits, trenches, or power shovel cuts, take the following steps:

1. Remove any overburden or surface soil that is to be wasted.
2. Shave off loose and dried soil to obtain a fresh surface for taking the sample.
3. Excavate a channel of uniform cross section from top to bottom, and deposit the soil onto a quartering cloth, canvas, or tarpaulin, as shown in figure 15-6.

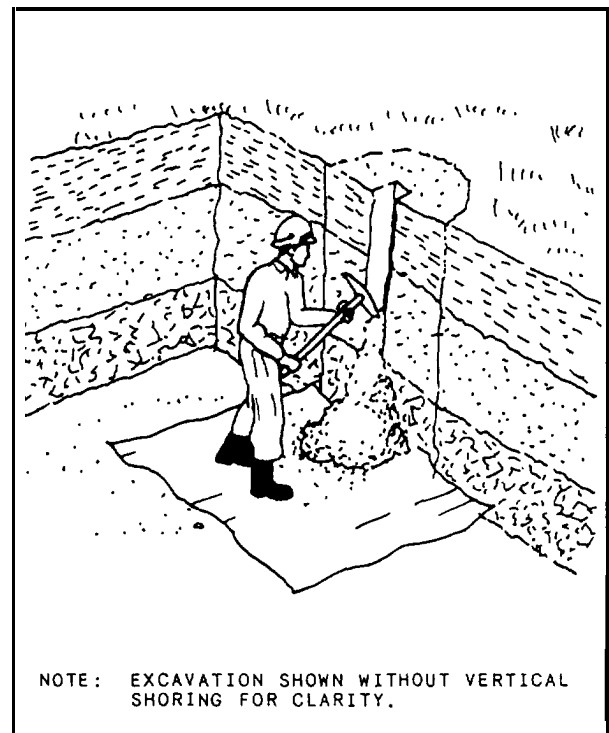


Figure 15-6.-Taking a composite sample with an exposed face.

Collect and bag all material removed to ensure that the sample contains the correct proportions. To take composite samples from auger holes, collect all material excavated from the hole after first removing the overburden. When taking representative composite samples from stockpiles or large windrows, take particular care. When material is dumped on large piles, the coarse material tends to roll to the bottom, leaving the finer material on the top. To compensate for this, take the sample from a full height strip after clearing the surface. To sample from a small windrow, excavate and bag material from a short section, as shown in figure 15-7.

Moisture Content Samples

The natural moisture content of soil is determined from samples taken in the field and placed in a container, which is then sealed to prevent loss of moisture by evaporation. Natural moisture content determinations are valuable in interpreting information obtained from test borings or pits,

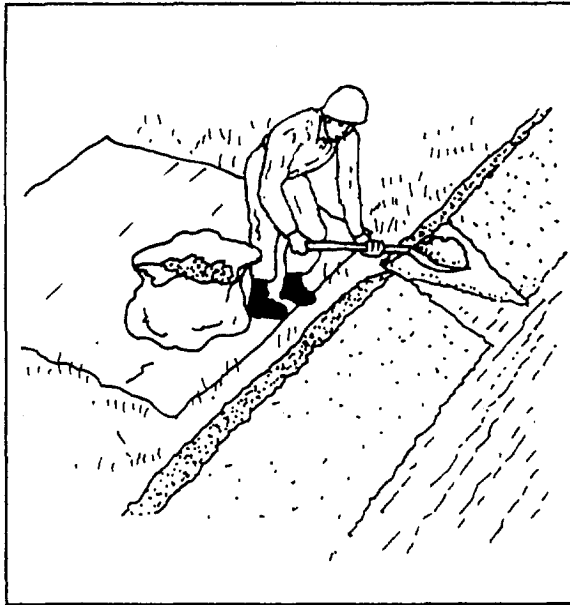


Figure 15-7. Taking a composite sample from a small windrow.

in drawing the soil profile, and in estimating the physical properties of soils encountered in the field.

Generally, 100 g of soil is enough to determine the moisture content of fine-grained soils. Larger samples are required for soils that contain gravel. Normally, moisture content samples are placed in metal dishes (canisters) that have tight-fitting covers; however, any other clean container that can be adequately sealed may be used. When the moisture content test is to be performed within 1 day after the sample is

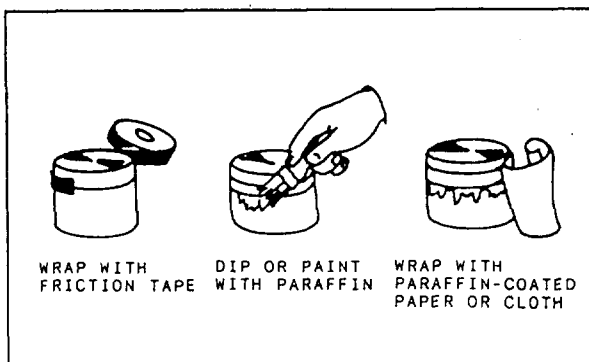


Figure 15-8. Sealing a container to retain moisture content of a sample.

obtained, sealing of the container is not required. If a longer time interval will elapse between sampling and testing, the containers may be sealed, as shown in figure 15-8.

UNDISTURBED SAMPLES

UNDISTURBED soil samples are those that are cut, removed, and packed with the least possible disturbance. They are samples in which the natural structures, void ratio, and moisture content are preserved as carefully as possible. Samples of this type are used for determining the density (unit weight) of soil in the laboratory and investigating the strength of undisturbed soils in the laboratory by the CBR or unconfined compression tests. These samples may be shipped to more completely equipped laboratories for shear, consolidation, or other strength tests.

Types of undisturbed samples are chunk samples, cut by hand with a shovel and knife, and cylinder samples, obtained by use of a cylindrical sampler or the CBR mold equipped with a sampling cutter. Expedient methods of obtaining cylinder samples are also used.

The method of sampling chosen depends upon the equipment available, the tests required, and the type of soil. All undisturbed samples must be handled with care. Cohesionless soil samples must be kept in the container until ready for testing, and the container should be handled without jarring or vibration. Some soils are too hard or contain too many stones to permit sampling with the cylindrical samplers and can be sampled only by cutting out chunks by hand. Taking of undisturbed samples frequently requires a great deal of ingenuity in adapting the sampling devices to job conditions and in devising schemes for their use. Whatever method is used, the sample must be taken and packed in the container for shipment without allowing its structure to change. Protection against change in moisture content during sampling and shipment is also required.

Chunk Samples

The simplest type of undisturbed sample is the chunk sample. It should be noted, however, that these can be obtained only from soils that will not deform, break, or crumble while being removed.

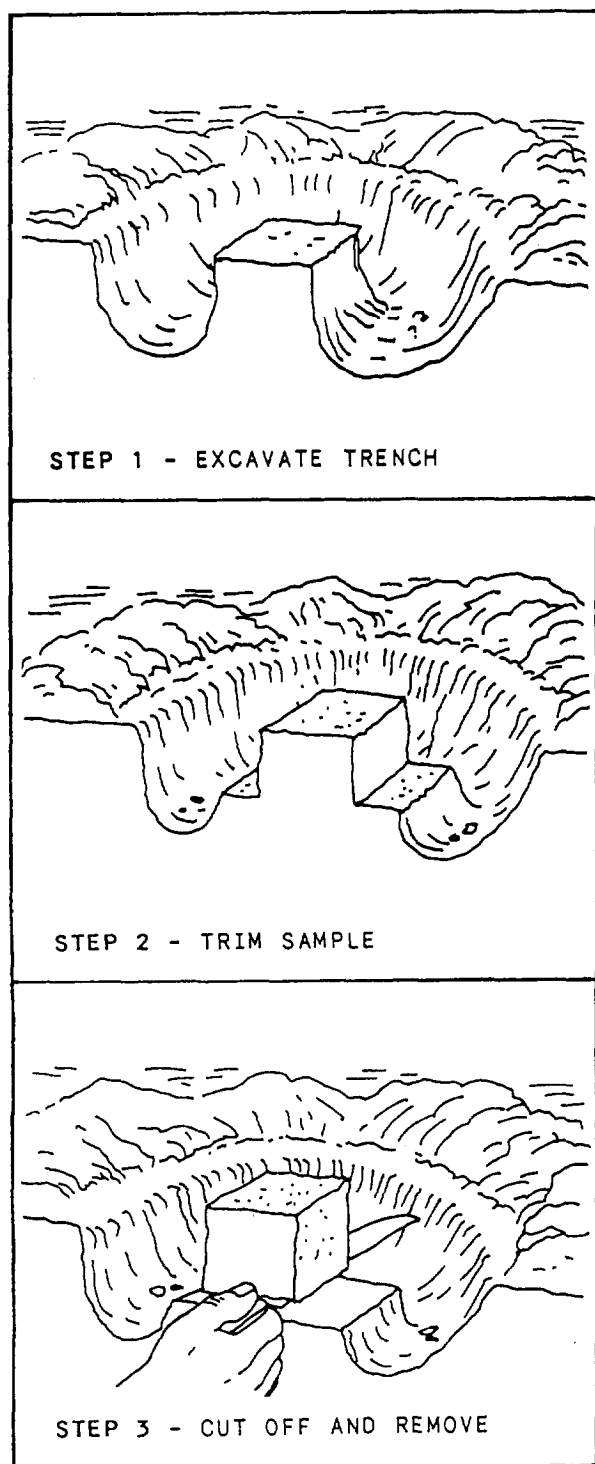


Figure 15-9. Taking a chunk sample from a level surface.

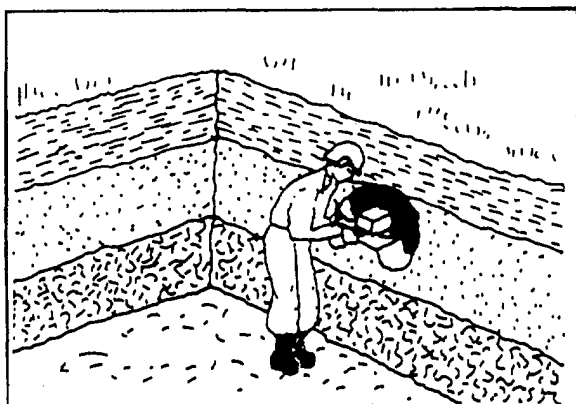
Figure 15-9 shows the process of taking a chunk sample from a level surface, such as a subgrade or the bottom of a test pit. After smoothing the ground surface and marking the outline of the chunk, the first step is to excavate a trench around the chunk. Then deepen the excavation and trim the sides of the chunk with a knife. Finally, using a knife, trowel, or hacksaw blade, cut off the chunk at the bottom and carefully remove it from the hole.

To take a chunk from the vertical face of a test pit or trench, as shown in figure 15-10, smooth the surface of the face and mark the chunk outline. Then excavate the soil from the top, sides, and back of the chunk. After shaping the chunk with a knife, cut it off and carefully remove it.

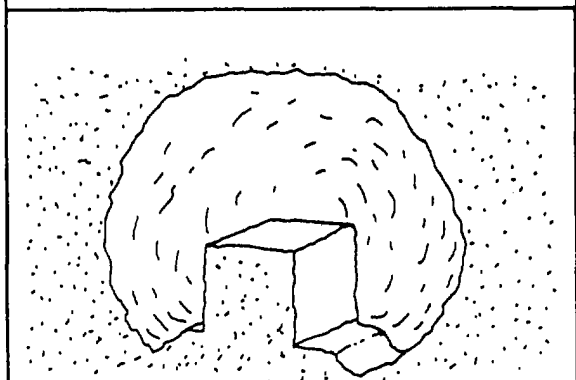
After removing the chunk sample from the hole, you need to seal it. One method is to apply three coats of melted paraffin, as shown in figure 15-11. Each coat is allowed to cool and become firm before the next coat is applied. This gives adequate protection for strong samples that will be used within a few days. When the samples are weak or may not be used within a few days, wrap them with cheesecloth or other soft cloth and seal them with paraffin (fig. 15-12). If cloth is not available, you can reinforce the sample with several loops of friction tape or twine. Then apply three coats of paraffin. Take extra precaution in these operations so that the sample is not damaged.

Another method is to dip the entire sample in melted paraffin after the first brush coat is applied and the sample is wrapped (fig. 15-13). This requires a larger container and more paraffin. However; this method provides a more uniform coating that, by repeated dippings, can be built up to 1/8 in. or more in thickness.

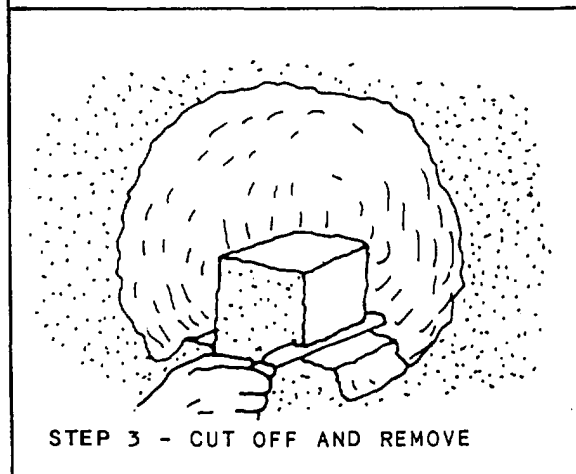
When samples are to shipped, as from a construction battalion's remote detail site to the battalion's main body site, additional protection is required. This can be accomplished by applying many coats of paraffin or by placing the chunk in a small



STEP 1 - EXCAVATE PIT AND SAMPLE TUNNEL



STEP 2 - TRIM SAMPLE



STEP 3 - CUT OFF AND REMOVE

NOTE: EXCAVATION SHOWN WITHOUT VERTICAL SHORING FOR CLARITY.

Figure 15-10.-Taking a chunk sample from a vertical face.

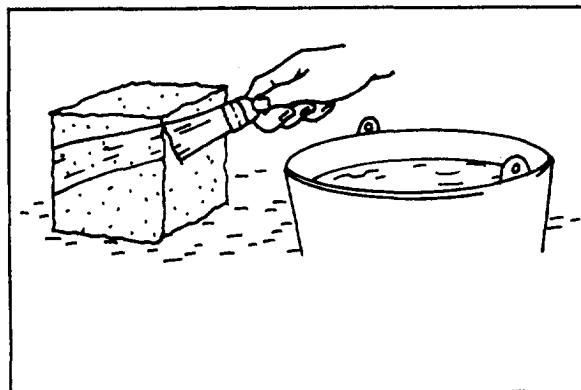


Figure 15-11.-Applying paraffin to seal a chunk sample.

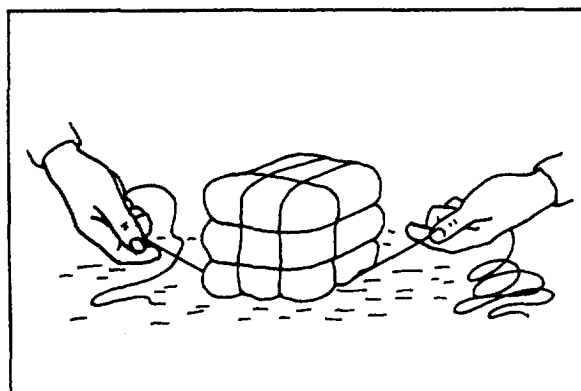


Figure 15-12.-Wrapping a weak chunk sample before final sealing.

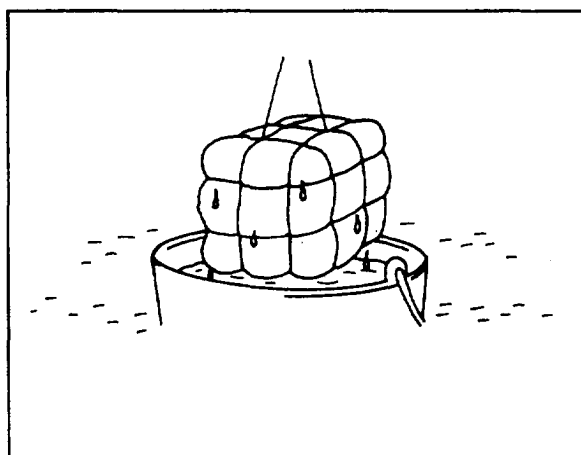


Figure 15-13.-Dipping a chunk sample into melted paraffin.

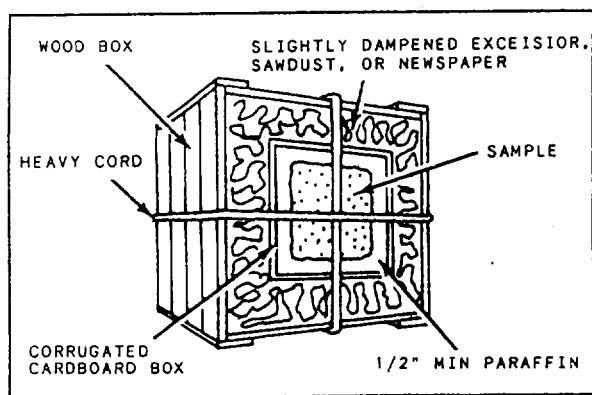


Figure 15-14. Packing a chunk sample for transportation or shipment to laboratory.

box and packing it, as shown in figure 15-14.

Cylinder Samples by CBR Mold

Figures 15-15 through 15-19 show a CBR compaction mold, fitted with a sampling collar (or cutter), and how to obtain a cylinder sample by using the CBR mold. This method may be used in taking an undisturbed sample from soft, fine-grained soils for undisturbed CBR or density tests.

When using this method, first smooth the ground surface and then press the sampling collar and mold into the soil with moderate

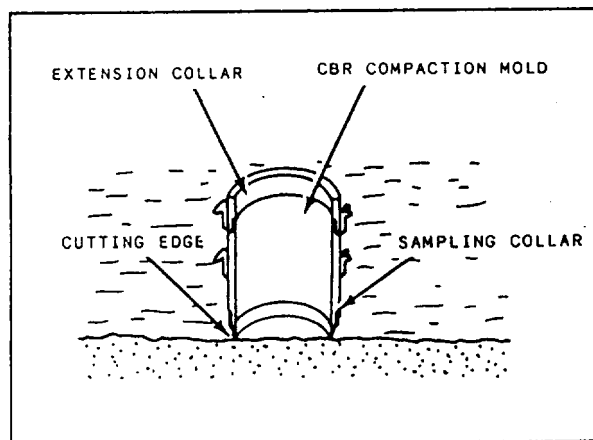


Figure 15-15. Section through a CBR mold.

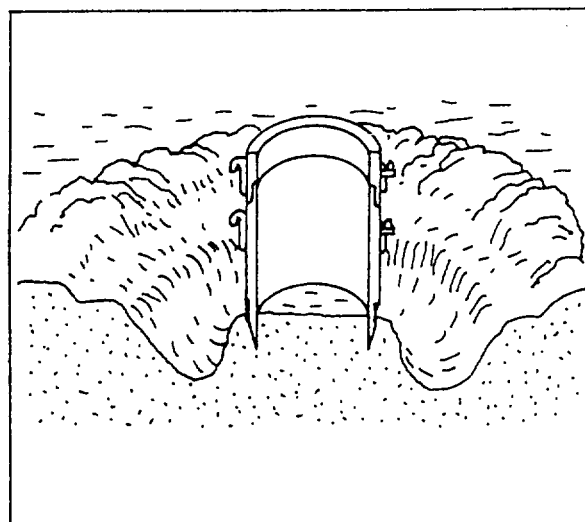


Figure 15-16. Trench cut around a cylinder.

pressure. Then excavate a trench around the cylinder and again press the mold down over the soil, using the hand driver or loading bar if necessary. You can improvise a loading bar from any suitably sized piece of timber. Trim the soil away from the sampling collar carefully with a knife, cutting downward and outward to avoid cutting into the

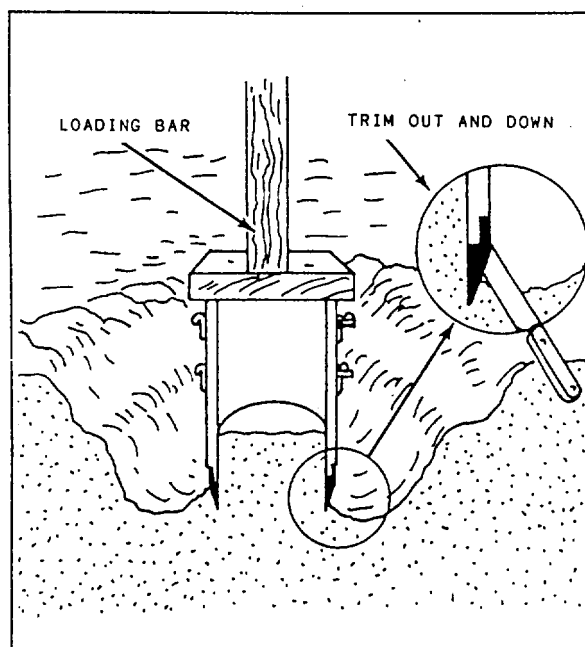


Figure 15-17. Using a loading bar to drive a cylinder.

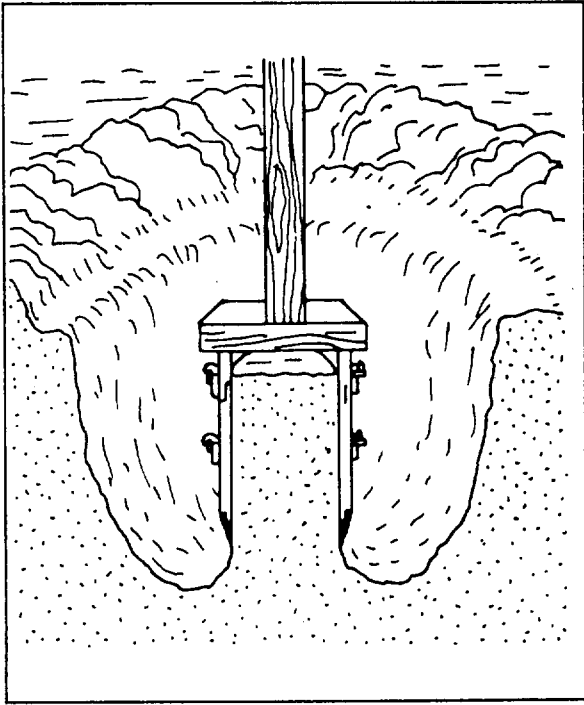


Figure 15-18. Cylinder in position before cutting a sample.

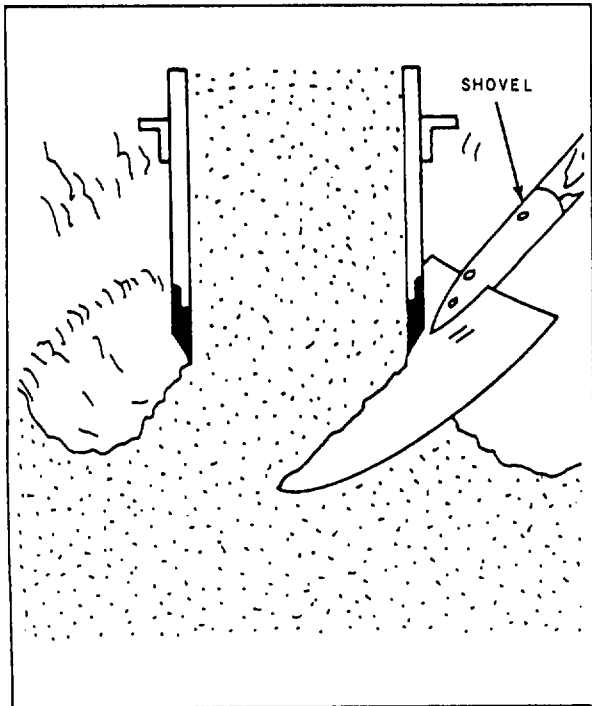


Figure 15-19. Cutting off a cylindrical sample.

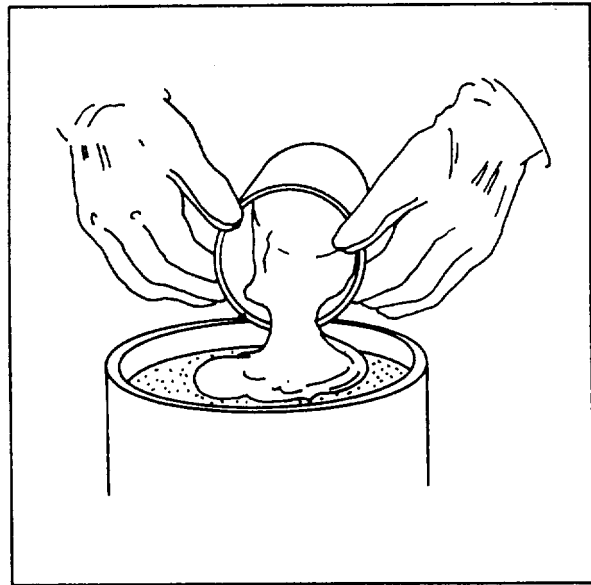


Figure 15-20. Sealing a sample in a CBR mold.

sample. You actually do the cutting to size with the sampling collar. You can force the sampler down with the field CBR jack; however, since this jack has only about 2 in. of travel, you would do better to use a truck jack, if available. In either case, you should not force the sampler down ahead of the trimming on the outside of the cylinder. Then excavate the trench deeper and repeat the process until the soil penetrates well into the extension collar. Finally, as shown in figure 15-19, cut off the sample at the bottom of the mold with a shovel, knife, or wire, and remove the mold and sample from the hole.

After removing the mold and sample from the hole, remove the upper collar of the mold, and trim the top surface of the sample down to approximately 1/2 in. from the top of the mold. Then fill this recess with paraffin, as shown in figure 15-20, to seal the end of the sample. Then, after you turn the mold over and remove the cutting edge, a similar recess is formed in the bottom of the sample. Fill this recess with paraffin also. If the sample is to be handled a great deal, you should overfill the ends with paraffin and then trim them exactly flush, using a straight-edge. Place boards over both ends and clamp them in place, using bolts, string, or wire, as

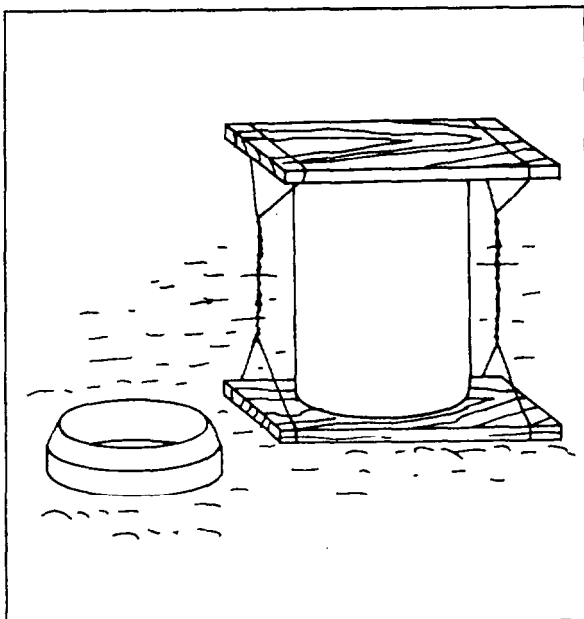


Figure 15-21. Protecting a sample in a CBR mold.

shown in figure 15-21. If the samples are to be transported some distance or will be handled quite a bit before testing, you should wrap them in cloth and soak them in paraffin layers.

QUARTERING SAMPLES

The process of reducing a representative soil sample to a convenient size or of dividing a sample into two or more smaller samples for testing is called **QUARTERING**. The procedures vary somewhat, depending upon the size of the sample.

Samples Weighing Over 100 Pounds

To quarter a sample of this size, first mix and pile the sample on a canvas, using a shovel. Place each new shovelful on the top-center of the preceding one so that the soil will be distributed evenly in all directions. Then flatten the sample to a circular layer of approximately uniform thickness. Next, insert a stick or length of pipe under the canvas and then lift it at both ends to divide the sample into two equal parts, as shown in figure 15-22. Remove the stick, leaving a fold in the canvas, and then reinsert it under the sample, but this time, at right angles to the first division. Again, lift the stick. This divides the sample into four parts, as shown in figure 15-23. Discard two diagonally opposite quarters, taking care to clean the fines from the canvas. Then remix the remaining material, taking alternate

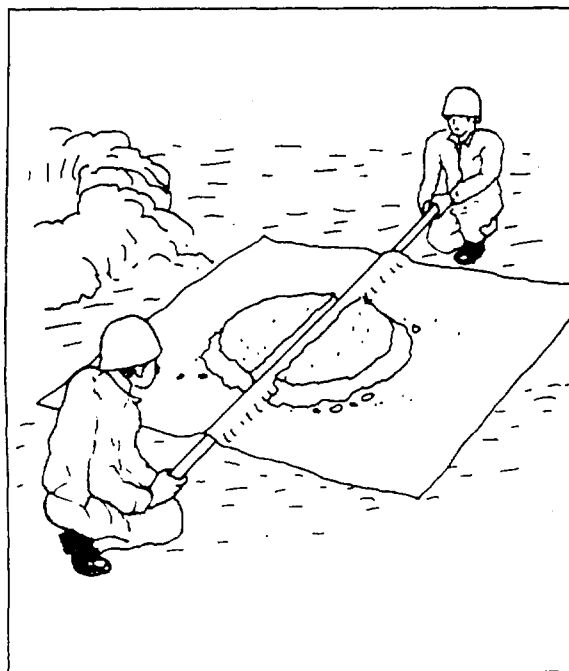


Figure 15-22. Halving the sample.

shovelful from each quarter. Repeat the quartering process as necessary to reduce the sample to the desired size.

Samples Weighing Between 25 and 100 Pounds

In quartering a sample of this size, pile the soil on the canvas and mix it by alternately lifting the

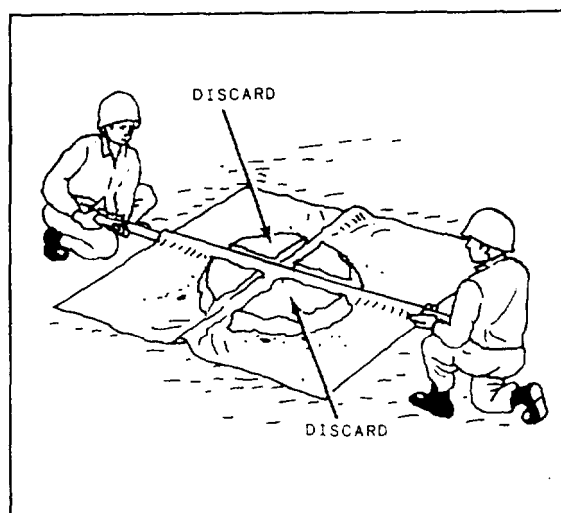


Figure 15-23. Quartering the sample.

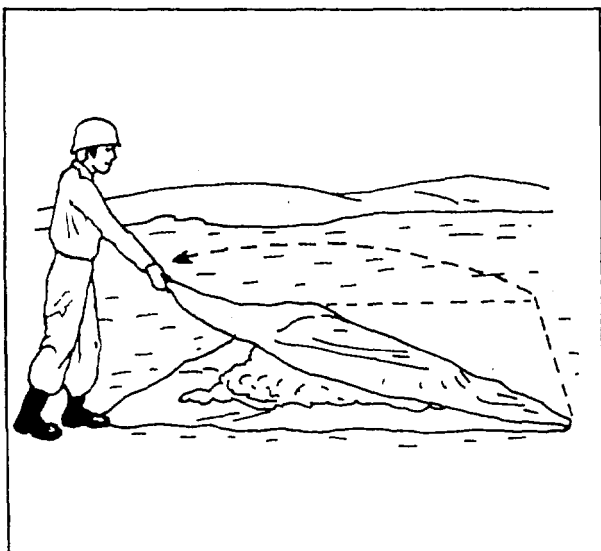


Figure 15-24.-Mixing a sample weighing 25 to 100 pounds.

corners of the canvas and pulling over the samples as if preparing to fold the canvas diagonally, as shown in figure 15-24. Then flatten and quarter the sample.

Samples Weighing Less Than 25 Pounds

For samples of this size, place the sample on the canvas or a clean sheet of paper. Mix it thoroughly with a trowel, form it into a conical shape, and then flatten it with the trowel. Using the trowel, divide the sample into quarters, and discard two diagonally opposite quarters, as shown in figure 15-25. Remix the remaining material, and repeat the process until the sample is the size needed for the test.

SOIL TESTING

In soil testing, the Navy follows procedures laid down by the American Society for Testing Materials (ASTM). Generally speaking, a complete soil test proceeds according to the following steps:

1. Determine the moisture content of representative samples. (This is preceded, of course, by the extraction of representative samples.)
2. Perform a mechanical analysis of the sample to determine the sizes of soil particles (or

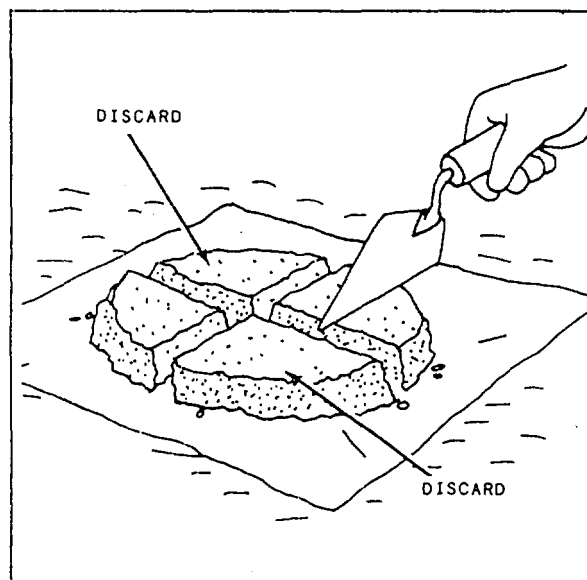


Figure 15-25.-Quartering a small sample.

grains) and the distribution of sizes; this means the percentage of each size contained in the whole mass.

3. Determine the specific gravity of representative samples. The specific gravity of a substance is expressed in terms of the ratio of the weight of a given volume of the substance to the weight of an equal volume of water. A cubic foot of water weighs 62.43 lb.

For soil, determine the absolute specific gravity; by this we mean determine the ratio of the weight of a dense volume (volume exclusive of air spaces) to the weight of an equal volume of water. A cubic foot of dry sand, for example, weighs about 100 lb. With air exhausted, however, a cubic foot of sand weighs about 165.44 lb. Therefore, the specific gravity of sand equals 165.44 divided by 62.43, or about 2.65.

4. If the soil is clay or a similar fine-grained soil, determine the Atterberg limits. Over a certain range of moisture content, a fine-grained soil remains plastic. A reduction below the bottom of the range causes the soil to become semisolid; an increase above the range causes it to become fluid. The upper moisture content is called the liquid limit; the lower is called the plastic limit.

5. Compaction testing is used to determine the moisture-density relationships; or, in other words, to determine what moisture content results in maximum compaction for a given compactive

effort. Compaction testing is not included in this TRAMAN but will be discussed at the EA2 level.

6. Field control testing is used to determine (1) the field moisture content (with an eye to reducing or increasing it to the optimum, if feasible) and (2) the point at which the specified density has been obtained by compaction. Field control testing is not included in this TRAMAN but will be discussed at the EA2 level.

DETERMINING MOISTURE CONTENT

Several methods of determining moisture content of soil are in existence. The most accurate is the ovendrying method, in which an electric or portable gasoline oven is used to dry the samples. A more expedient method is the calcium carbide gas pressure method. This method, however, is less accurate and should always be approved by your supervisor. A third method uses the NUCLEAR MOISTURE-DENSITY METER. Since specialized training and operator certification are required, use of the nuclear moisture-density meter will not be discussed in this training manual.

Ovendrying Method

As noted above, this is the most accurate method used to determine moisture content. The apparatus and procedures used are discussed below.

APPARATUS.— Laboratory apparatus for moisture content determination includes the following items:

- A balance (fig. 15-26) for weighing material in grams. There are 453.6 g in a pound.
- Several small circular moisture boxes (called cans) (fig. 15-26) for placing samples in to weigh and dry.
- An electric oven or a portable gasoline oven to dry samples.
- Crucible tongs.

In the absence of an electric oven or gasoline oven, you may dry the materials in a frying pan held over an ordinary stove or hot plate. The

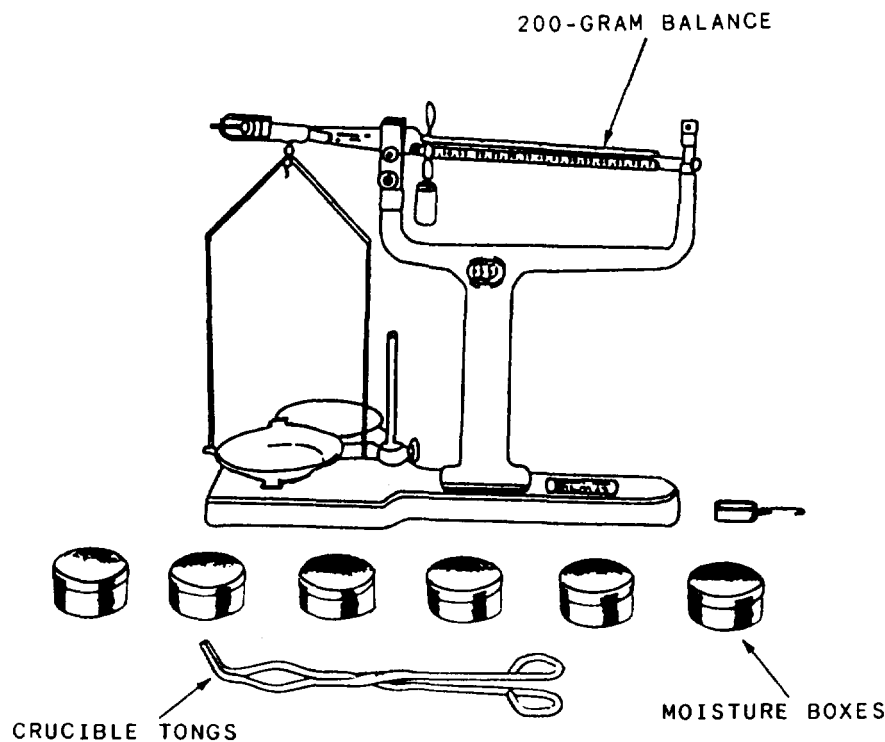


Figure 15-26. Apparatus for determining moisture content.

disadvantage here is that the temperature is hard to control and the organic material in the sample may be burned; this would cause a slight to moderate inaccuracy in the result. The thermostat on an electric oven can be set to the desired temperature.

PROCEDURE.— Before beginning the tests, weigh each of the moisture boxes and record the weight by can number. Record this weight as tare weight (weight that allows for a deduction of the

can). Then fill each can with a sample and weigh the can (with lid on) and contents.

Remove the lid and place the can, contents, and lid in the oven or pan to dry. In an electric oven, maintain the temperature between 212°F and 230°F (105°C ± 10°C); dry the sample for at least 8 hr—even longer for clay or silt. Then weigh the dry can, contents, and lid.

Record the results on a form like the one shown in figure 15-27. In the example shown in

SOIL MOISTURE CONTENT						DATE <i>16 June 19 -</i>
PROJECT <i>Faulkner Airbase</i>						
EXCAVATION NUMBER <i>3</i>		SAMPLE NUMBER <i>FA-P2-1</i>		FORMULA Water Content, $w = \frac{W}{D} \times 100$		
TEST <i>Natural Soil Moisture Content</i>						UNIT
RUN NUMBER	<i>1</i>	<i>2</i>	<i>3</i>			
TARE NUMBER	<i>5</i>	<i>10</i>	<i>1</i>			
A. WEIGHT OF TARE + WET SOIL	<i>189.3</i>	<i>175.0</i>	<i>223.0</i>			<i>g</i>
B. WEIGHT OF TARE + DRY SOIL	<i>170.0</i>	<i>162.1</i>	<i>204.0</i>			<i>g</i>
C. WEIGHT OF WATER, W_w (A.-B.)	<i>19.3</i>	<i>12.9</i>	<i>19.0</i>			<i>g</i>
D. WEIGHT OF TARE	<i>44.0</i>	<i>42.9</i>	<i>45.2</i>			<i>g</i>
E. WEIGHT OF DRY SOIL, W_s (B.-D.)	<i>126.0</i>	<i>119.2</i>	<i>158.8</i>			<i>g</i>
WATER CONTENT, w	<i>15.3 %</i>	<i>10.8 %</i>	<i>12.0 %</i>			
TEST						UNIT
RUN NUMBER						
TARE NUMBER						
A. WEIGHT OF TARE + WET SOIL						
B. WEIGHT OF TARE + DRY SOIL						
C. WEIGHT OF WATER, W_w (A.-B.)						
D. WEIGHT OF TARE						
E. WEIGHT OF DRY SOIL, W_s (B.-D.)						
WATER CONTENT, w						
TEST						UNIT
RUN NUMBER						
TARE NUMBER						
A. WEIGHT OF TARE + WET SOIL						
B. WEIGHT OF TARE + DRY SOIL						
C. WEIGHT OF WATER, W_w (A.-B.)						
D. WEIGHT OF TARE						
E. WEIGHT OF DRY SOIL, W_s (B.-D.)						
WATER CONTENT, w						
REMARKS						
TECHNICIAN (Signature) <i>James Perry</i>		COMPUTED BY (Signature) <i>James Perry</i>		CHECKED BY (Signature) <i>Thomas Connors</i>		

Figure 15-27.-Data sheet for moisture content tests.

figure 15-27, three tests (called runs) were made, using cans numbered 5, 10, and 1. Online D (weight of tare), record the weight of each can. Note that although the cans are identical in appearance, they vary slightly in weight. Online A (weight of tare and wet soil), record the weight of each can with wet contents. On line B (weight of tare and dry soil), record the weight of each can with contents after drying.

Online C, Ww (weight of water in the soil sample) was obtained by subtracting (B) from (A). On line E, Ws (weight of dry soil) was obtained by subtracting (D) from (B).

The line labeled “water content, w,” shows the results obtained by substituting the known values in the following formula:

$$w = \frac{Ww}{Ws} \times 100$$

The average of these three values, or 12.7 percent, is the value of w (percentage of moisture content) for the sample.

Calcium Carbide Gas Pressure Method

This method uses a 26-g SPEEDY MOISTURE TESTER to determine the moisture content of soils, fine aggregates, sand, and clay. By using the SPEEDY tester, the moisture content can be determined in the laboratory or field in from 45 sec to 3 min, depending upon the material being tested. The tester operates on the principle of a calcium carbide reagent (reactive agent) being introduced into the free moisture of the soil sample. The resulting chemical reaction creates a gas that is contained in a sealed chamber, the pressure of which can be measured with the built-in gas pressure gauge.

APPARATUS.— The SPEEDY moisture test set (fig. 15-28) includes the SPEEDY tester, a balance, half-weight reagent, measuring scoop, brushes, cleaning cloth, and two 1 1/4-in. steel balls.

PROCEDURE.— The procedure for determining moisture content using the SPEEDY MOISTURE TESTER is as follows:

1. Weigh a 26-g sample of soil.
2. Place the soil sample and two 1 1/4-in. steel balls in the large chamber.

FIGURE REMOVED

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for electronic media.

Figure 15-28.—SPEEDY moisture test set.

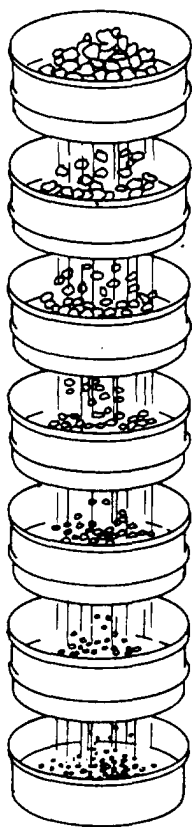


Figure 15-29.-Varying sieve sizes.

3. Place three scoops (24 g) of reagent in the cap. Then, with the pressure vessel in a horizontal position, insert the cap into the pressure vessel and tighten the clamp to seal the cap to the unit.

4. Raise the moisture tester to a vertical position so that the reagent falls into the vessel.

5. Hold the moisture tester horizontally; vigorously shake the device with a rotating motion for 10 sec to put the steel balls into orbit around the inside circumference; then rest for 20 sec. Repeat the shake-rest cycle for a total of 3 min. Do not allow the steel balls to fall against either the cap or orifice leading to the dial; this may cause damage.

6. Holding the tester horizontally at eye level, read and record the dial reading as the percent of moisture by wet mass.

7. When the sample is dumped, examine it for lumps. If the soil sample is not completely broken down, increase the time limit (shaking unit) by 1 min on the next test.

8. To determine the percentage of moisture by dry mass (ovendry moisture percentage), read the direct reading obtained in No. 6 above into a calibration curve that is also supplied with the test set.

MECHANICAL ANALYSIS

Mechanical analysis is the determination of grain sizes and the percentage distribution of each size. A complete mechanical analysis is accomplished in two parts: sieve analysis and hydrometer analysis.

Sieve Analysis

A sieve analysis is applicable to soils that are larger than the No. 200 sieve or that contain small amounts of material passing the No. 200 sieve. You can conduct the sieve analysis either on the entire sample or on the sample after the fines are removed by prewashing. The apparatus and procedures used to conduct a sieve analysis are described below.

APPARATUS.— Typical sieve analysis apparatus includes a gram weighing balance and a number of sieves with apertures of varying sizes used to determine grain sizes (fig. 15-29). Sieves may be of the ordinary circular SIFTER type (usually about 8 in. in diameter) or the ROCKER type, which consists of a rocker frame in which screens with apertures of various sizes can be placed.

The sieve used for analysis is the so-called standard sieve. A standard sieve has a square aperture. Screen sizes are designated as follows: A sieve with fewer than four apertures to the linear inch is designated by the size of an aperture; for example, a 1/4-in., 1/2-in., 3/4-in., or 1-in. sieve.

A sieve with four or more apertures to the linear inch is designated by a number that represents the number of apertures to the linear inch. A No. 4 sieve, for example, has four apertures to the linear inch, a No. 6 has six apertures, and so on. The finest sieve used is a No. 200, with 200 apertures to the linear inch and an aperture size slightly smaller than one two-hundredth of an inch square.

To conduct a sieve analysis, you need an electric or hand-operated sieve shaker.

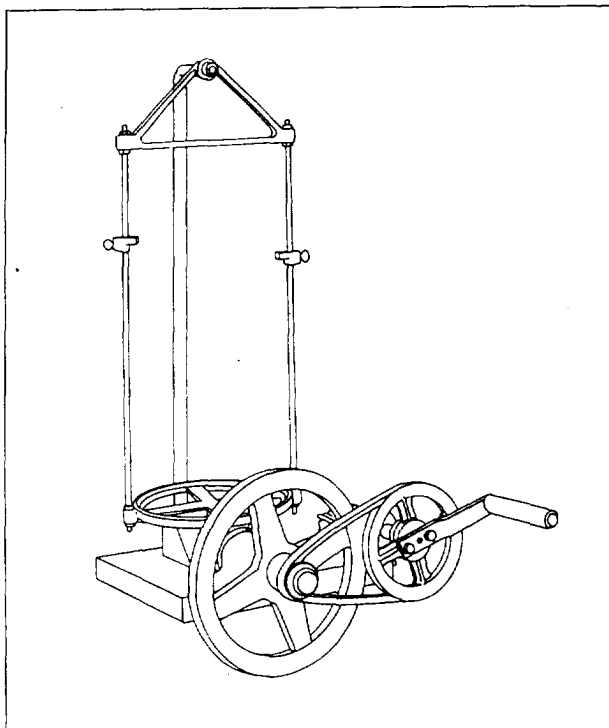


Figure 15-30.-Hand-operated sieve shaker.

The hand-operated shaker is shown in figure 15-30.

SIEVE ANALYSIS, DRY.— The minimum sample weight required for a sieve analysis is dependent upon the maximum particle size in the sample as follows:

Maximum particle size (sieve opening)	Minimum dry weight of test specimen
3 in.	6,000 g
1 1/2 in.	3,000 g
3/4 in.	1,500 g
3/8 in.	600 g
No. 4	200 g

Samples that contain cohesive soil, which forms hard lumps, must be prewashed. This procedure is described later. Other samples are analyzed DRY by the following procedure:

1. Oven-dry the sample.
2. Break up lumps. For coarse material, use a rolling pin on a clean, hard, smooth surface.

For fine material, use a mortar and pestle (usually a part of the laboratory apparatus). Take care not to crush individual grains. The object is to separate aggregations of clustering grains.

3. Weigh the sample.

4. Select and weigh the sieves and pan to be used in the test. The sieve selection varies according to the type of soil being tested. The following is a selection commonly used:

3 in. (76.2 mm)	No. 10 (2.00 mm)
1 1/2 in. (38.1 mm)	No. 20 (1.21 mm)
1/2 in. (12.7 mm)	No. 40 (0.42 mm)
3/8 in. (9.52 mm)	No. 100 (0.149 mm)
No. 4 (4.76 mm)	No. 200 (0.074 mm)

Stack (nest) the sieves one on top of the other such that the largest sieve is on top. The coarsest sieve actually recorded is the next above the first one that retains any material. The weight recorded as retained on this sieve is 0 g; the weight recorded as passing it is the total weight of the sample.

5. Place the sieve pan under the stack of sieves; place the total sample in the top sieve and shake. The shaking interval depends on the amount of fine material. Five minutes is usually enough for most coarse-grained soils, and 15 min is enough for most fine-grained soils.

6. Remove the sieves from the shaker. Starting with the first to retain any material, carefully weigh each sieve with the retained material. Subtract the weight of the sieve from the combined weight of the sieve and material to determine the weight of the material retained on each sieve. Finally, determine the weight of the material that reached the pan; that is, that passed the No. 200, or finest, sieve.

Enter the results on a data sheet like the one shown in figure 15-31. In this analysis, all the material (359.1 g) passed the 3/8-in. sieve; none was retained on this one. The No. 4 retained 51.0 g. This means that 308.1 g (359.1 – 51.0) passed this sieve. You can see how the weight passing was determined from the weight retained in each subsequent case. In column d, the percent passing is computed for each sieve by multiplying the weight passing by 100 and dividing the result by the total weight of the sample.

SIEVE ANALYSIS DATA			DATE 11 July 19 -
PROJECT <i>Fraunce Theater</i>		EXCAVATION NUMBER <i>2</i>	SAMPLE NUMBER <i>FT-P1-1</i>
DESCRIPTION OF SAMPLE <i>25 lb. bag sample</i>			PREWASHED <input type="checkbox"/> YES <input checked="" type="checkbox"/> NO
WEIGHT ORIGINAL SAMPLE (g) <i>359.1</i>	WEIGHT AFTER PREWASHING ¹ (g)	WASHING LOSS ² (g)	
SIEVE OR-SCREEN a	WEIGHT RETAINED ON SIEVE (g) b	PASSING SIEVE	
		WEIGHT (g) c	PERCENT d
	0		100
<i>3/4</i>			
<i>1/2</i>			
<i>3/8</i>		<i>359.1</i>	<i>100.0</i>
<i>No. 4</i>	<i>51.0</i>	<i>308.1</i>	<i>85.8</i>
<i>10</i>	<i>40.9</i>	<i>267.2</i>	<i>74.4</i>
<i>20</i>	<i>83.3</i>	<i>183.9</i>	<i>51.2</i>
<i>40</i>	<i>75.4</i>	<i>108.5</i>	<i>30.2</i>
<i>100</i>	<i>49.9</i>	<i>58.6</i>	<i>16.3</i>
NUMBER 200	<i>47.4</i>	<i>11.2</i>	<i>3.1</i>
A. WEIGHT SIEVED THROUGH NO. 200 (g) <i>11.1</i>		ERROR (Original weight - total weight of fractions)(g) <i>359.1 - 359.0 = 0.1</i>	
B. WASHING LOSS ¹ (g)			
TOTAL PASSING NO. 200 (g) (A. + B.) C. <i>11.1</i>		PERCENT ERROR $\left(\frac{\text{Error (g)}}{\text{Original weight (g)}} \times 100 \right) = .028\%$	
TOTAL WEIGHT OF FRACTIONS (Total of all entries in Col. b + C) <i>359.0</i>			
REMARKS			
TECHNICIAN (Signature) <i>Paul Massin</i>		COMPUTED BY (Signature) <i>Paul Massin</i>	CHECKED BY (Signature) <i>John Stark</i>

¹For prewashed samples only. ²Maximum particle size.

Figure 15-31.-Data sheet for dry sieve analysis.

The total weight of fractions plus the weight of the material that reached the pan comes to 359.0 g. The weight of the sample originally was 359.1 g; there is an error here of 0.1 g. At the lower right, you can see how the percentage of error is computed. The maximum permissible percentage of error is normally (\pm) 1 percent. If the percentage exceeds the maximum, the test must be rerun. For an error smaller than the maximum permissible, correction is made by adding the value of the error to the largest amount listed as retained. The value of the error in this case is 0.1 g. The largest amount retained is 83.3 g for the No. 20 sieve. This amount would be changed to 83.4 g.

SIEVE ANALYSIS WITH PREWASHING.— When inspection indicates that a sample contains an excessively high portion of superfine material (material that passes the No. 200 sieve), analysis with prewashing is done as follows:

1. Oven-dry the sample.
2. Weigh and record the total weight after cooling.
3. Place the sample in a clean pan and add clean water until it is completely covered. Allow it to soak until it is completely disintegrated—from 2 to 12 hr. Stir to break up lumps and hasten the action.
4. Wash the material thoroughly on a No. 200 sieve under running water and discard the material that passes.
5. Oven-dry and reweigh. Record the difference between this weight and the original weight as washing loss.
6. Continue as for sieve analysis, dry.

Figure 15-32 shows a data sheet for sieve analysis with prewashing. The oven-dry weight of the original sample was 75.0 g; the oven-dry weight after prewashing was 55.0 g; therefore, the washing loss was 75.0 - 55.0 or 20.0 g. The sum of the weights retained (53.0 g, the total of column b) plus the 2.0 g that, in spite of prewashing, was still left in the sample to pass the No. 200 sieve, equals 55.0 g. This was the original weight after prewashing. Therefore, no error was made.

Hydrometer Analysis

As you learned in the preceding discussion, the determination of grain size distribution by sieve analysis is limited to those materials larger than the No. 200 (0.074-mm) sieve. For uses such as soil classification, this is sufficient since grain size distribution is not used to classify fine-grained soils. For determination of frost susceptibility,

however, the distribution of particles smaller than the No. 200 sieve is necessary. A soil is considered frost susceptible if it contains 3 percent or more by weight of particles smaller than 0.020 mm in diameter. Frost susceptibility should always be considered in areas subject to substantially freezing temperatures, since repeated freezing, and subsequent thawing, of water in the soil can seriously affect the ability of the soil to support a structure. Hydrometer analysis is the test used to determine the grain size distribution of the soils passing the No. 200 sieve.

Hydrometer analysis is based on Stokes' law, which relates the terminal velocity of a free-falling sphere in a liquid to its diameter. The relation is expressed by the following equation.

$$V = \frac{G_s - G_w}{18n} D^2$$

Where:

- V = terminal velocity
- G_s = specific gravity of solids
- G_w = specific gravity of the liquid in which the sphere is falling
- n = viscosity of the liquid
- D = diameter of the sphere

It is assumed that Stokes' law can be applied to a mass of dispersed soil particles of various shapes and sizes. Larger particles settle more rapidly than the smaller ones. The hydrometer analysis is an application of Stokes' law that permits the calculation of the grain size distribution in silts and clays, where the soil particles are given the sizes of equivalent spherical particles.

The density of a soil-water suspension depends upon the concentration and specific gravity of the soil particles. If the suspension is allowed to stand, the particles will gradually settle out of the suspension, and the density will be decreased. The hydrometer is the instrument used to measure the density of the suspension at a known depth below the surface. The density measurement, together with knowledge of specific gravity of the soil particles, determines the percentage of dispersed soil particles in suspension at the time and depth of measurement. Stokes' law is used to calculate the maximum equivalent particle diameter for the material in suspension at this depth and for the elapsed time of settlement. A series of density measurements at known depth of suspension and at known times of settlement gives the percentages of particles finer than the diameters given by Stokes' law. Thus the series of readings will reflect the amount of different sizes of particles in the fine-grained soils. The particle diameter (D) is

SIEVE ANALYSIS DATA			DATE <i>11 July 19-</i>
PROJECT <i>Fraunce Theater</i>		EXCAVATION NUMBER <i>2</i>	SAMPLE NUMBER <i>FT-P2-1</i>
DESCRIPTION OF SAMPLE <i>25 lb bag sample</i>			PREWASHED <input checked="" type="checkbox"/> YES <input type="checkbox"/> NO
WEIGHT ORIGINAL SAMPLE (g) <i>75.0</i>	WEIGHT AFTER PREWASHING ¹ (g) <i>55.0</i>	WASHING LOSS ² (g) <i>20.0</i>	
SIEVE OR SCREEN a	WEIGHT RETAINED ON SIEVE (g) b	PASSING SIEVE	
		WEIGHT (g) c	PERCENT d
	0		100
<i>No. 10</i>		<i>75.0</i>	<i>100.0</i>
<i>20</i>	<i>8.7</i>	<i>66.3</i>	<i>88.4</i>
<i>40</i>	<i>29.0</i>	<i>37.3</i>	<i>49.8</i>
<i>100</i>	<i>13.3</i>	<i>24.0</i>	<i>31.1</i>
NUMBER 200	<i>2.0</i>	<i>22.0</i>	<i>29.4</i>
A. WEIGHT SIEVED THROUGH NO. 200 (g) <i>2.0</i>		ERROR (Original weight - total weight of fractions)(g) <i>none</i>	
B. WASHING LOSS ¹ (g) <i>20.0</i>			
TOTAL PASSING NO. 200 (g.) (A + B) C <i>22.0</i>		PERCENT ERROR $\frac{\text{Error (g)}}{\text{Original weight (g)}} \times 100$ <i>none</i>	
TOTAL WEIGHT OF FRACTIONS (Total of all entries in Col. b + C) <i>75.0</i>			
REMARKS			
TECHNICIAN (Signature) <i>Paul Massin</i>		COMPUTED BY (Signature) <i>Paul Massin</i>	CHECKED BY (Signature) <i>John Stark</i>

¹ For prewashed samples only. ² Maximum particle size.

Figure 15-32.-Data sheet for sieve analysis with prewashing.

calculated from Stoke's equation using corrected hydrometer reading and a nomographic chart.

The procedures used to perform the hydrometer analysis are not discussed in this TRAMAN but are contained in ASTM D 422.

SPECIFIC GRAVITY TESTING

The specific gravity of a solid substance is the ratio of the weight of the solid to the weight of an equal volume of water. In dealing with soils,

the specific gravity is necessary for certain tests, such as hydrometer analysis. It is also necessary for computations involving volume and weight relationships. The specific gravity of a soil mass can be expressed in one of three different forms as follows:

SPECIFIC GRAVITY OF SOLIDS (G_s) is the ratio of the weight in air of a given volume of soil particles to the weight of an equal volume of distilled water, both at a stated temperature. The specific gravity of solids is only applied to that fraction of a soil that passes a No. 4 sieve.

APPARENT SPECIFIC GRAVITY (G_a) is the ratio of the weight in air of a given volume of the impermeable portion of soil particles to the weight in air of an equal volume of distilled water, both at a stated temperature. The impermeable portion of a porous material, such as most large soil grains, includes the solid material plus impermeable pores or voids within the particles.

BULK SPECIFIC GRAVITY (G_m) is the ratio of the weight in air of a given volume of permeable material (including permeable and impermeable voids) to the weight of an equal volume of distilled water at a stated temperature.

Sample Selection

For specific gravity tests, the soil samples may be either disturbed or undisturbed. Care must be taken, however, to ensure that representative samples are obtained. When the sample contains both large and small particles, the sample should be separated on a No. 4 sieve. Then the specific gravity of the fine fraction is determined separately from the coarse fraction. A composite specific gravity for the entire soil sample is then calculated in the manner to be described later.

For samples smaller than the No. 4 sieve, it is easier to begin the test with an ovoidried sample. However, some soils, particularly those with high organic content, should be tested at their natural water content; the ovoidried weight determined at the end of the test.

Specific Gravity of Solids

As discussed earlier, the specific gravity of solids is applied to soil that passes a No. 4 sieve. However, when the specific gravity is to be used in conjunction with hydrometer analysis, it is determined only on the fraction that passes a No. 200 sieve. In either case, the specific gravity may be determined for soil at natural water content or ovoidried.

APPARATUS.— A 500-milliliter (ml) volumetric flask is required for this test. For the discussion in this TRAMAN, it is assumed that the flask has been calibrated. This means that the weight of the flask and water has been calibrated over a range of temperatures that would likely be encountered in the laboratory. As a matter of interest, calibration procedures are located in ASTM D 854. Some other apparatus used to perform test are as follows:

- Balance, 2,000-g capacity
- Balance, 200-g capacity
- Cans, moisture content
- Dishes, evaporating
- Funnel
- Mortar and pestle
- Pump, vacuum (optional)
- Stirrer, soil dispersion (optional)
- Thermometer, general laboratory

PROCEDURE.— AS mentioned previously, you can perform the specific gravity test on soils at natural water content. When possible, however, you should first oven-dry the sample, as this makes it easier to perform the test. The procedure for performing the specific gravity test is as follows:

1. Record all identifying information regarding the sample on a data sheet similar to figure 15-33. Also, record identifying information for the flask and dish (or moisture can) that will be used for the test.

2. Air-or oven-dry the sample and breakup all lumps with a mortar and pestle. About 50 g of clay and about 100 g of coarser samples are the usual quantities.

3. Weigh and record the tare weight of a moisture can. Then fill the can with the dry sample; oven-dry and determine the weight to the nearest 0.01 g. This weight minus the tare weight is the weight of the dry soil (W_s) entered in block 6g of figure 15-33. This weight is critical to the accuracy of the test. **YOU MUST TAKE GREAT CARE NOT TO LOSE ANY OF THE MATERIAL DURING THE REMAINDER OF THE TEST.**

4. Transfer the material to the volumetric flask, using a funnel. Use a battery filler, or syringe, to CAREFULLY wash ALL material from the can and funnel into the flask.

5. Fill the flask two-thirds full of clean water (for exact analysis use distilled or demineralized water). Allow the material to soak from 4 to 6 hr, except for clean, sandy soil, which does not require soaking.

SPECIFIC GRAVITY TESTS				1. DATE <i>10 JAN 1991</i>	
2. PROJECT <i>PARKING APRON EXPANSION</i>		3. BORING NUMBER <i>TEST PIT</i>	4. JOB NUMBER	5. EXCAVATION NUMBER	
6. SPECIFIC GRAVITY OF SOLIDS (G_s)					
W E I G H T M E A S U R E M E N T	a. SAMPLE OR SPECIMEN NUMBER		<i>TP-1</i>		
	b. FLASK NUMBER		<i>1</i>		
	c. TEMPERATURE OF WATER AND SOIL (T, °C)		<i>28.5</i>		
	d. DISH NUMBER		<i>3</i>		
	e. DISH + DRY SOIL		<i>123.0</i>		
	f. DISH		<i>41.0</i>		
	g. DRY SOIL		W_s	<i>82.0</i>	
	h. FLASK + WATER AT T, °C		W_{bw}	<i>637.85</i>	
	i. $W_s + W_{bw}$		<i>719.85</i>		
	j. FLASK + WATER + IMMERSED SOIL		W_{bws}	<i>690.5</i>	
k. DISPLACED WATER, $W_s + W_{bw} - W_{bws}$		<i>29.35</i>			
l. CORRECTION FACTOR		K	<i>0.9979</i>		
m. $(W_s/K) + (W_s + W_{bw} - W_{bws})$		G_s	<i>2.79</i>		
7. APPARENT (G_a) AND BULK (G_m) SPECIFIC GRAVITY					
W E I G H T M E A S U R E M E N T	a. SAMPLE OR SPECIMEN NUMBER		<i>TP-1</i>		
	b. TEMPERATURE OF WATER AND SOIL (T, °C)		<i>25.0</i>		
	c. TARE + SATURATED SURFACE-DRY SOIL		<i>1200.0</i>		
	d. TARE		<i>225.0</i>		
	e. SATURATED SURFACE-DRY SOIL		B	<i>945.0</i>	
	f. (WIRE BASKET + SOIL) IN WATER		<i>1994.0</i>		
	g. WIRE BASKET IN WATER		<i>1420.0</i>		
	h. SATURATED SOIL IN WATER		C	<i>574.0</i>	
	i. TARE AND DRY SOIL		<i>1149.0</i>		
	j. TARE		<i>230.0</i>		
k. DRY SOIL		A	<i>919.0</i>		
l. CORRECTION FACTOR		K	<i>0.9988</i>		
m. $(AK) + (A - C)$ (APPARENT)		G_a	<i>2.66</i>		
n. $(AK) + (B - C)$ (BULK)		G_m	<i>2.47</i>		
8. REMARKS					
<i>RETAINED No. 4 - 60%</i> <i>PASSED No. 4 - 40%</i> <i>COMPOSITE $G = 2.71$</i>					
9. TECHNICIAN (Signature)		10. COMPUTED BY (Signature)		11. CHECKED BY (Signature)	
<i>Carl L. Lacey</i>		<i>FAZ SHERMAN</i>		<i>EAR Kester</i>	

DD Form 1208, DEC 86 Previous editions are obsolete.

Figure 15-33.-Data sheet for specific gravity test.

6. Attach a vacuum pump to the flask and exhaust all air. The exhausted air is indicated by rising bubbles. For most soils, 30 min of pumping is enough. A heavy clay, however, may require as much as 2 hr of pumping. As

an alternative to the vacuum pump, the air may be exhausted by gently boiling the suspension for at least 10 min. To aid in the removal of entrapped air, occasionally roll the flask. A slow boil should be used, as fast

Table 15-3.-Relative Density of Water and Correction Factor (K) at Various Temperatures

TEMP °C	RELATIVE DENSITY	CORRECTION FACTOR, K	TEMP °C	RELATIVE DENSITY	CORRECTION FACTOR, K	TEMP °C	RELATIVE DENSITY	CORRECTION FACTOR, K
18.0	0.99862	1.0004	23.0	0.99756	0.9993	28.0	0.99626	0.9980
18.5	0.99852	1.0003	23.5	0.99744	0.9992	28.5	0.99611	0.9979
19.0	0.99843	1.0002	24.0	0.99732	0.9991	29.0	0.99597	0.9977
19.5	0.99833	1.0001	24.5	0.99720	0.9990	29.5	0.99582	0.9976
20.0	0.99823	1.0000	25.0	0.99707	0.9988	30.0	0.99567	0.9974
20.5	0.99813	0.9999	25.5	0.99694	0.9987	30.5	0.99552	0.9973
21.0	0.99802	0.9998	26.0	0.99681	0.9986	31.0	0.99537	0.9971
21.5	0.99791	0.9997	26.5	0.99668	0.9984	31.5	0.99521	0.9970
22.0	0.99780	0.9996	27.0	0.99654	0.9983	32.0	0.99505	0.9968
22.5	0.99768	0.9995	27.5	0.99640	0.9982	32.5	0.99490	0.9967

boiling may cause material to be boiled out of the flask.

7. After all air has been exhausted, and the flask and contents have cooled, add more de-aired, distilled water until the flask is filled to the ring marked on the neck. To ensure all air is exhausted, a second boiling may be necessary.

8. Next, dry the outside of the flask and any moisture above the water surface inside the flask.

9. Weigh the flask and contents to the nearest 0.01 g, and record the information in block 6j (fig. 15-33). This is W_{bws} .

10. Immediately after weighing, stir the suspension to assure even temperature distribution. Immerse a thermometer to mid-depth of the flask, and read the temperature of the soil-water suspension. Record this temperature in block 6c (fig. 15-33).

11. Finally, with the data entered on the data sheet, compute the specific gravity using the following formula:

$$G = \frac{W_s K}{W_s + W_{bw} - W_{bws}}$$

where:

W_s = Dry weight of the sample

K = Correction factor based on the density of water at 20°C. You can get this factor from table 15-3 by selecting the correction factor that corresponds to the temperature obtained in Step 10, above.

W_{bw} = Weight of the flask filled with water only, at test temperature. You can get this value from a calibration curve, or table, previously prepared for the flask used in the test.

W_{bws} = Weight of the flask, water, and sample at test temperature

Bulk and Apparent Specific Gravity

The following discussion applies to determination of bulk and apparent specific gravity. Bulk specific gravity is usually determined for the coarser materials that are retained on a No. 4 sieve. Large stones may be determined individually.

SAMPLE PREPARATION.— Separate the sample on a No. 4 sieve, and use the material retained on that sieve for the test. Approximately 2 kg is required. Ensure the sample is a representative sample.

In preparing the sample, first wash the material to remove dust and coatings. Then immerse and soak the sample in water for 24 hr. Just before making the test, dry the sample to a saturated-surface-dry condition. Do this by rolling the sample in art absorbent cloth to remove excess surface water. You may wipe large particles individually. When saturated-surface-dry, the surface may still appear damp. Take care to avoid excessive evaporation during the surface drying.

APPARATUS.— Apparatus for the test is as follows:

Balance, 5 kg or larger, sensitive to 0.1 g

Wire mesh basket, approximately 8 in. in diameter and 8 in. high; 2-mm (No. 6) or finer mesh

Container, large enough to permit immersing the wire basket

Suitable equipment for suspending the wire basket from the center of balance scale pan

Thermometer, general laboratory

PROCEDURE.— Perform the test in the following steps. You must complete the first step as quickly as possible after surface-drying the sample.

1. Determine the weight of the saturated-surface-dry sample and container. This weight minus the tare weight of the container is the weight of the saturated-surface-dry soil that you should enter in block 7e (fig. 15-33).

2. Determine the weight of the wire basket suspended in water. Record this weight in block 7g (fig. 15-33).

3. Place the sample in the basket and immerse the basket and sample in water. (Hang the basket from the balance and support the container so that the basket hangs freely in the water.) Read the weight and record it in block 7f (fig. 15-33). Subtract the weight of the empty basket suspended in water, Step 2 above, to determine the weight of the saturated soil in water. Record this weight in block 7h (fig. 15-33).

4. Measure and record the temperature of the water and soil. Enter this temperature in block 7b (fig. 15-33).

5. Determine the oven-dry weight of the sample and enter the results in block 7k (fig. 15-33).

6. From the recorded information, you may now calculate both the bulk specific gravity (G_m) and the apparent specific gravity (G_a) using the following formulas:

$$G_m = \frac{\text{weight of dry soil in air} \times K}{\text{weight of saturated sample in air} - \text{weight of sample in water}} = \frac{AK}{B-C}$$

and

$$G_a = \frac{\text{weight of dry soil in air} \times K}{\text{weight of dry soil in air} - \text{weight of sample in water}} = \frac{AK}{A-C}$$

Specific Gravity of Composite Sample

After determining the specific gravity of solids (G_s) and the apparent specific gravity (G_a), you can calculate the specific gravity of an entire soil sample (both larger and smaller than

a No. 4 sieve). To do so, use the following formula:

$$G = \frac{100}{\frac{\% \text{ Passing No. 4 Sieve}}{G_s} + \frac{\% \text{ Retained No. 4 Sieve}}{G_a}}$$

Enter this composite specific gravity in the remarks block of the data sheet. Note, too, that you should also enter in the remarks block the percent of materials that is retained on, or passes, the No. 4 sieve.

Comment Regarding Correction Factor (K)

Refer again to figure 15-33. In this figure, you see the values of G_s , G_a , and G_m that were obtained using the correction factor (K). Now, if you were to disregard K and recalculate, you would obtain values of the following: $G_s = 2.7939$, $G_a = 2.6638$, and $G_m = 2.4471$. As you can see, these values, obtained without the correction factor, are hardly different than the values obtained with the correction factor. Therefore, unless unusually accurate precision is required, the correction factor may be disregarded.

ATTERBERG LIMITS

As you previously learned, fine-grained soils are not classified under the Unified Soils Classification System on the basis of grain size distribution. They are, instead, classified on the basis of plasticity and compressibility. The Atterberg limits are laboratory classification criteria used for classifying fine-grained soils. As an EA3, you will be responsible for the performance of the Atterberg limits test.

A clay or related fine-grained soil, when dry or nearly dry, has a semisolid consistency. As moisture content increases, a point is reached where the material has a plastic (putty like) consistency. This point is called the PLASTIC LIMIT (PL). As moisture content continues to increase, the material remains plastic over a certain range. However, at a point called the LIQUID LIMIT (LL), the consistency of the material finally changes to semiliquid.

The upper and lower limits of the plastic range (that is, the liquid and plastic limits) are called ATTERBERG LIMITS. These limits were named after a Swedish scientist who developed the concept of the limits. The liquid limit (LL) is simply

the moisture content (W_L) at the upper limit of the plastic range, expressed as a percentage. The plastic limit (PL) is the moisture content at the lower limit of the plastic range.

Test Equipment

Figure 15-34 shows equipment for determining the Atterberg limits of a soil sample. The LIQUID LIMIT TESTING DEVICE consists of a brass bowl mounted on a box type of apparatus. When you turn the crank, the apparatus elevates the bowl containing the sample and then drops it downward a specific distance onto the hard-rubber anvil of the testing device. Each of these drops is called a BLOW. We will explain the purpose of the procedure as we describe the test.

Test Procedure

The liquid and plastic limit tests normally are conducted only on the portion of the soil that passes the No. 40 sieve. A few particles that are large enough to be retained on the No. 40 sieve do not cause serious difficulty. However, it is generally faster to remove these larger particles by hand by kneading the soil between the fingers. If the percentage of particles retained on the No. 40 sieve is higher, these particles must be removed by passing the soil through the No. 40 sieve. Do not oven-dry or subject the sample to any artificial drying before you process or test it.

Soak the sample in water for 24 hr before washing. Then wash it through the No. 40 sieve and collect it in a large evaporating dish or collecting can. Oven-dry the material retained on the sieve, then dry-sieve it through the No. 40 sieve. Combine the portion dry sieved through the No. 40 sieve with the material washed through the sieve; the combined material is used for the tests. Break up soil particles that are lumping together or adhering to aggregate particles and separate them by rubbing them with your hands.

Next, dry the sample to approximately the liquid limit by decanting or blotting the water off, by evaporating it off (taking care to stir the soil frequently during evaporation), or by a combination of both procedures.

After this, place the soil mass in the liquid limit testing device cup, and divide it into sections by a central groove made with the grooving tool (fig. 15-34). The water content at the liquid limit is the water content at which the soil mass makes contact for a distance of 1/2 in. when the cup is dropped 25 times (25 blows) for a distance of 1 cm (0.3937 in.) at a rate of two drops per second. First, adjust the machine for this drop distance as follows:

A metric gauge is located on the handle of the grooving tool. The machine has an ADJUSTMENT PLATE and a pair of ADJUSTMENT

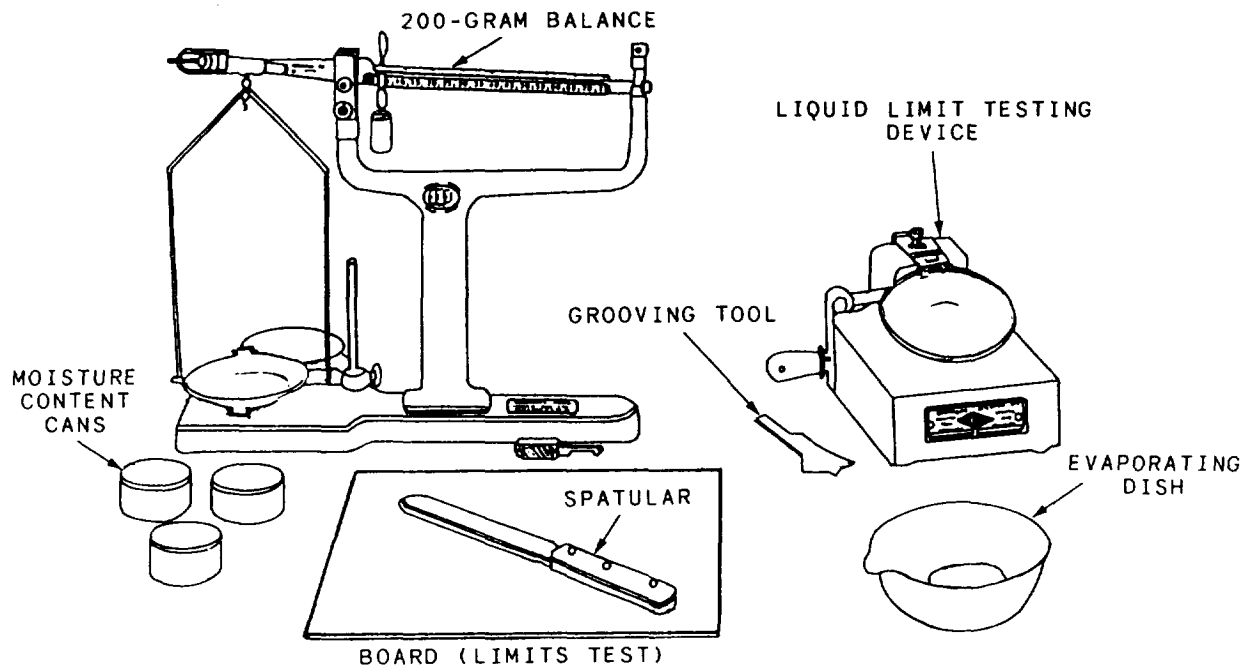


Figure 15-34.-Apparatus for determining Atterberg limits.

SCREWS. Manipulate the screws to adjust the height to which the cup is lifted. The point on the cup that comes into contact with the anvil of the machine should be exactly 1 cm above the anvil (the upper surface of the hard-rubber base of the machine). Check the adjustment by turning the crank at a rate of two drops per second. You should hear a slight click when the adjustment is correct.

Steps in the test procedure are as follows:

1. From the prepared test material, take a sample that weighs about 100 g and place a portion in the cup above the spot where the cup rests on the base. Squeeze the sample and spread it with as few strokes of the spatula as possible, taking care to prevent the air bubbles from getting trapped within the mass. With the spatula, level the soil as you trim it to a depth of 1 cm at the point of maximum depth. Divide the soil in the cup by making a groove with the grooving tool along the center line of the cam follower or hook that holds the cup. When you make the groove, hold the cup in your left hand with the hook upward, and draw the grooving tool, beveled edge forward, through the material downward away from the hook. With some soils (especially sandy soils and soils containing organic matter), it is not possible to draw the grooving tool through the specimen without tearing the sides of the groove. In such cases, make the groove with

a spatula, using the tool only for final shaping. When made correctly, the groove is wedge-shaped in section; it is open at the bottom for a distance equal to the width of the tip of the grooving tool.

2. Attach the cup to the carriage and turn the crank at a rate of two revolutions per second. Count the blows as you continue to turn the crank until the two halves of the soil cake come into contact at the bottom of the groove along a distance of about 1/2 in. (fig. 15-35). Record the number of blows required to close the groove in this manner.

After you record the number of blows, remove the cup from the testing device. Remix and regroove the sample. Place the cup again in the testing device and repeat the test. If the number of blows on the second test differs from the number on the first by one or less, record both numbers on the data sheet and consider the test finished. If the number of blows on the second test differs by more than one, repeat the test until three successive tests give a reasonably consistent sequence. The average of the three is taken as the number required for the closure.

3. Remove a slice of soil approximately the width of the spatula (say about 10 g), extending from the edge of the soil cake at right angles to

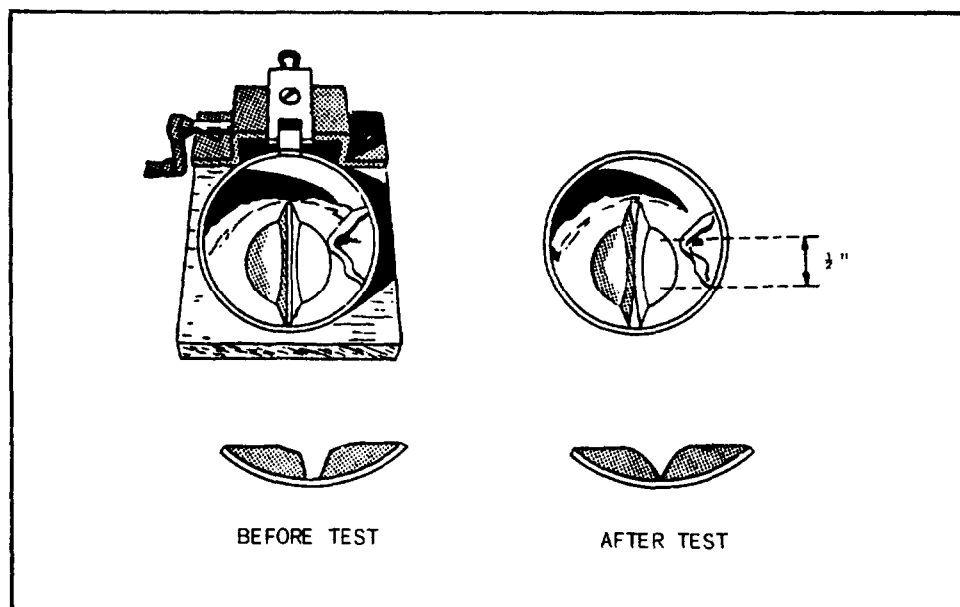


Figure 15-35.-Liquid limit test.

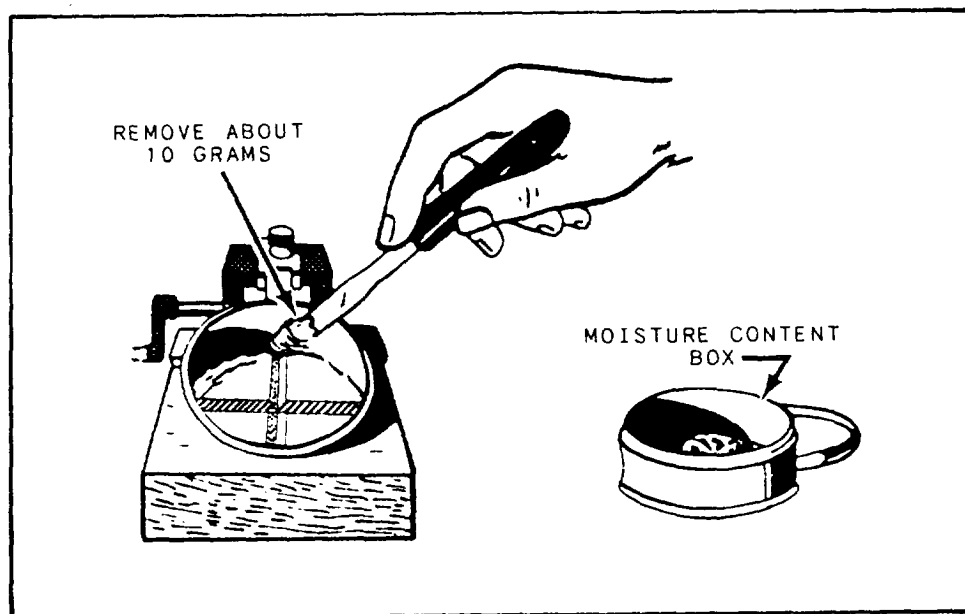


Figure 15-36.-Removing sample portion for moisture content.

the groove (fig. 15-36). Place this in a moisture content can, weigh it, and record the weight. Oven-dry and record the difference in weights. This is the weight of the water content.

4. Transfer the remaining soil in the cup to the evaporation dish. Wash and dry the cup and grooving tool. Reattach the cup in preparation for the next run.

5. Run at least five tests on each soil, with two closures above, two closures below, and one closure at or near the 25-blow line. An ideal spread is closures at 16, 23.5, 29, and 33 blows. If each test is perfect, the plotted line through all points is shown as a straight line. If some tests are imperfect, the operator can usually get good results by using the three plotted points lying most nearly in a straight line.

To determine the liquid limit, plot a FLOW CURVE on a graph like the one shown in figure 15-37. It is a semilogarithmic graph, in which the vertical coordinates are water content and the horizontal coordinates are number of blows. The flow curve is a straight line plotted as nearly as possible through three or more of the plotted points.

In figure 15-37, the first-run sample was tested three times for an average number of 16 hammer blows. The water content was 47.3 percent. On the graph, 16 and 47.3 are the coordinates of one

of the three Xs shown plotted. The second-run sample indicated 24 hammer blows and 46.6 percent water content; these are the coordinates of another of the Xs plotted to the right. Coordinates for the third X are the hammer blows and water content for the third-run sample. The coordinates of the rest of the plotted points are as indicated by the hammer blows and water content for the succeeding runs. The plotted points in the graph may not form a straight line; however, the liquid limit line (or flow curve) is a straight line, passing nearly through the mean of the plotted points (fig. 15-37). The usual recommendation is that five or six trials be made so that the results are more representative.

The liquid limit (LL) is the water content for 25 blows; it is therefore indicated by the point of intersection between the flow curve and the vertical line representing 25 blows. The water content indicated is about 46.4 percent. This, when rounded off to 46, is the liquid limit.

The plastic limit of soil is the lowest water content at which the soil just begins to crumble when rolled into threads 1/8 in. in diameter, at slowly decreasing water content. First, prepare the sample as follows:

If you need only the plastic limit, take a quantity of soil weighing about 15 g from the prepared material in the evaporating dish. Place this air-dried soil in an evaporating

ATTERBERG LIMITS DETERMINATION					DATE 1 JUNE 19-		
PROJECT BRITT AIRFIELD			EXCAVATION NUMBER		SAMPLE NUMBER B-P3-1		
LIQUID LIMIT, w_L							
RUN NUMBER	1	2	3	4	5	6	
TARE NUMBER	41	42	43	44	45	46	
A. WEIGHT OF WET SOIL + TARE	44.41	44.89	41.07	41.27	41.17	40.91	
B. WEIGHT OF DRY SOIL + TARE	41.08	41.52	38.16	38.39	38.32	38.08	
C. WEIGHT OF WATER, w_w (A.-B.)	3.33	3.37	2.91	2.88	2.85	2.83	
D. WEIGHT OF TARE	34.04	34.29	31.88	32.06	32.01	31.80	
E. WEIGHT OF DRY SOIL, w_s (B.-D.)	7.04	7.23	6.28	6.33	6.31	6.28	
WATER CONTENT, w_c ($\frac{w_w}{w_s} \times 100$) %	47.3	46.6	46.3	45.5	45.2	45.0	
NUMBER OF BLOWS	15-17-16	23-24	29-28-30	33-33	37-38	41-42	
LL	46		PL	18		PI=LL-PL	28

PLASTIC LIMIT, w_p					NATURAL WATER CONTENT
RUN NUMBER	1	2	3		
TARE NUMBER	45	46	47		48
P. WEIGHT OF WET SOIL + TARE	56.21	55.15	60.60		58.72
G. WEIGHT OF DRY SOIL + TARE	55.90	54.89	60.10		57.82
H. WEIGHT OF WATER, w_w (P.-G.)	0.31	0.26	0.50		0.90
I. WEIGHT OF TARE	64.10	53.40	57.43		55.02
J. WEIGHT OF DRY SOIL, w_s (G.-I.)	1.80	1.49	2.67		2.80
WATER CONTENT, w_c ($\frac{w_w}{w_s} \times 100$)	17.2	17.4	18.7		32.1
PLASTIC LIMIT, I_p (Average w)				18	
REMARKS					
TECHNICIAN (Signature) <i>William Deni</i>		COMPUTED BY (Signature) <i>William Deni</i>		CHECKED BY (Signature) <i>Joseph Stepler</i>	

Figure 15-37.-Data sheet, Atterberg limits determination.

dish and thoroughly mix it with distilled water, adding water until the soil mass becomes plastic enough to be shaped into a ball easily. Take a portion of the ball weighing about 8 g for the sample.

Steps in the test procedure are as follows:

1. Squeeze and form the 8-g test sample into an oval-shaped mass. Roll this mass between the

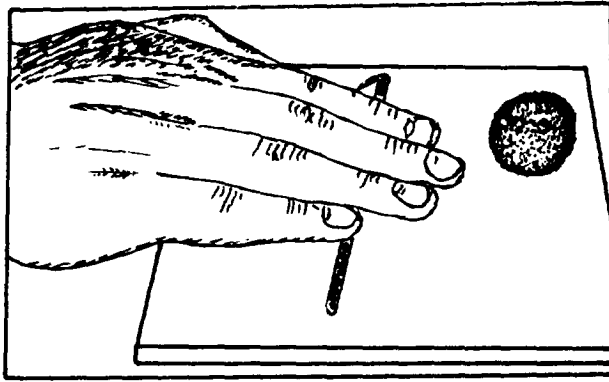


Figure 15-38.-Roll or thread test.

fingers and the test board (fig. 15-38) with just enough pressure to roll the mass into a thread of uniform diameter throughout its length. The rate of rolling should be between 80 and 90 strokes a minute, considering a stroke to be one complete motion of the hand forward from and back to the starting point.

2. When the diameter of the thread has been reduced to 1/8 in., break the thread into six or eight pieces (fig. 15-39). Squeeze the pieces together between the thumbs and fingers of both hands into a uniform mass roughly oval in shape, and again roll out into a thread. Continue this alternate rolling to a thread 1/8 in. in diameter, breaking, combining together, and rerolling. Do this until the thread crumbles under the pressure required for rolling and the soil can no longer be rolled into a thread. The crumbling may occur when the diameter of the thread is still greater than 1/8 in. This is considered a satisfactory end point, provided the soil has previously been rolled into a 1/8-in. thread at least once.

3. Gather the portions of the crumbled soil together, place it in the moisture content can, and determine the water content from the difference in weight before and after you oven-dry it.

4. Repeat the process on at least two additional specimens. All three tests should agree within 1 percent.

The plastic limit is simply the determined water content.

Plasticity Index

The PLASTICITY INDEX (PI) of a soil is the numerical difference between its liquid limit and its plastic limit; that is, $PI = LL - PL$. The PI that appears in figure 15-37 means plasticity index.

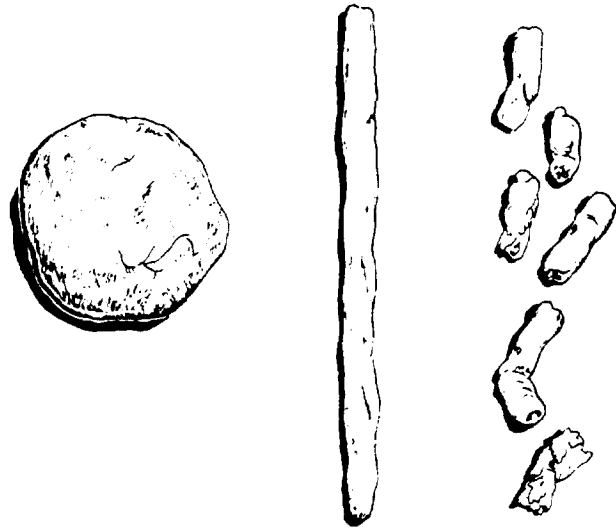


Figure 15-39.-Roll or thread test sample, before and after crumbling.

CONCRETE TESTING

Before delving into the remainder of this chapter, you may find it helpful to return to chapter 7 and review the topics concerning concrete. As you recall, in that chapter you studied concrete in terms of its use as a construction material, and you learned of the properties and requirements that comprise a good concrete. You also know that when concrete is placed in the field on a construction project, the concrete used must satisfy certain specified requirements. It is towards those properties and various requirements that concrete testing is directed.

CONCRETE TESTS

In concrete testing, as in soils testing, no single test will provide all of the information required. Rather, there is an array of tests that must be performed. The following describes those tests with which an EA is most commonly concerned.

Aggregate Tests

In order to provide the strongest and most durable concrete, the aggregate contained in the mixture must be the best possible in terms of gradation, shape, strength, and cleanliness. During the design of a concrete mixture, the aggregate selected for use must adequately meet those requirements. To determine this, various tests are performed. These include tests for

Table 15-4.-Recommended Slumps for Various Types of Construction

Types of construction	Slump, inches*	
	Maximum	Minimum
Reinforced foundation walls and footings	5	2
Plain footings, caissons, and substructure walls	4	1
Reinforced slabs, beams, and walls	6	3
Building columns	6	3
Pavements	3	2
Heavy mass construction	3	2
Bridge decks	4	3
Sidewalks, driveways, and slabs on ground	6	3
*When high-frequency vibrators are used, the values may be decreased approximately one-third; in no case should the slump exceed 6 inches.		

gradation; specific gravity, absorption, and surface moisture; impurities, such as organic material, clay, or other water-absorbing particles; and soundness, which is the property of an aggregate to resist disintegration due to freezing and thawing. Although these tests are not included in this TRAMAN, you may refer to NAVFAC MO-330, *Materials Testing*, should you desire to learn more about them.

Slump Tests

As you are aware from your study of chapter 7, **WORKABILITY** is the relative ease or difficulty of placing and consolidating concrete. When placed, all concrete should be as stiff as possible, yet maintain a homogeneous, voidless mass. Too much stiffness, however, makes it too difficult or impossible to work the concrete into the forms and around reinforcing steel. On the other hand, too fluid a mixture is also detrimental. The measure of the workability or consistency of concrete is its slump, which is a design consideration that is inversely proportional to the stiffness of the mix. As shown in table 15-4, the recommended values for slump vary for different types of construction. To measure slump, either during the preparation of concrete trial batches or as a quality control check during construction, testers perform slump tests. The procedures for performing slump tests will be explained later in this chapter.

Strength Tests

In the design of concrete structures, the design engineer specifies given strengths that the final concrete products must be capable of attaining. When trial batches are prepared during mix design or as a quality control measure to ensure that concrete mixed or delivered in the field satisfies those specified strengths, the following tests are performed.

COMPRESSION TEST.— Compression tests are conducted to determine the compressive strength of concrete (or its ability to resist a crushing force). In this test, a standard test load is applied parallel to the longitudinal axis of a premolded and properly cured concrete cylinder of a standard size. When the test is properly conducted, a maximum load is obtained at the point at which the cylinder ruptures. With this maximum load, the compressive strength, measured in pounds per square inch (psi), can be easily calculated. Although the test procedures will be covered at the EA2 level, the procedures used to prepare the cylinders for testing will be discussed later in this chapter.

FLEXURAL STRENGTH TEST.— The flexural strength (modulus of rupture) test determines the flexural strength of concrete (or its ability to resist a breaking force). In this test, a standard

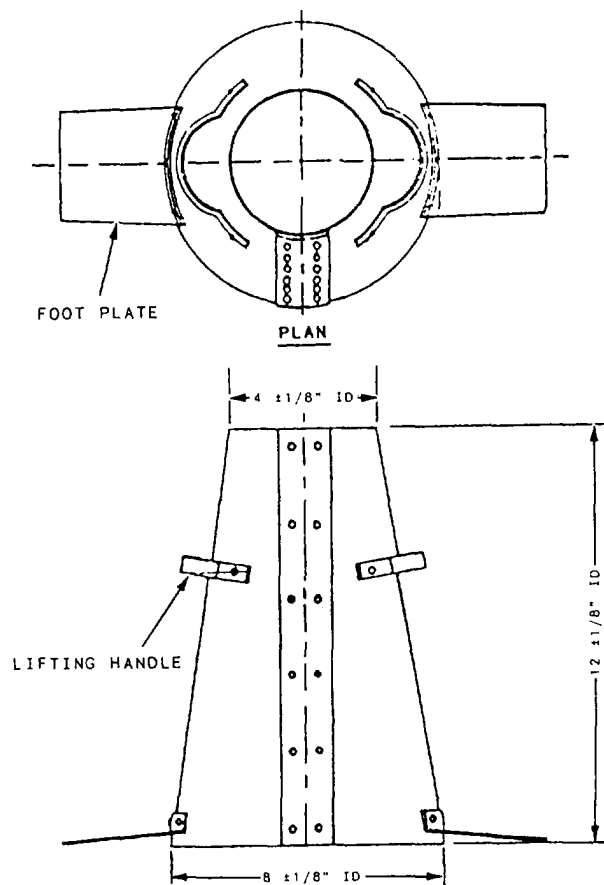


Figure 15-40.-Slump cone.

test load is applied perpendicular to the longitudinal axis of a standard size, premolded, and-properly cured concrete beam. From this test, the flexural strength, expressed in terms of modulus of rupture and given in psi, can be readily calculated. As with the compression test, only the procedures to prepare the test beams correctly will be discussed in this TRAMAN.

SLUMP TESTS

The slump test is performed on newly mixed concrete. To perform the test, you need a slump cone and a tamping rod. The slump cone (fig. 15-40) should be made of galvanized steel, 12 in. in height, with a base opening 8 in. in diameter and the top opening 4 in. in diameter. Both the top and bottom openings are perpendicular to the vertical axis of the cone. The tamping rod is a straight, steel rod that is 5/8 in. in diameter and approximately 24 in. in length. One end of the rod is rounded to a diameter of 5/8 in. (Do not substitute a piece of rebar.)

Sampling Procedures

Sampling (or obtaining) concrete for the slump test should be accomplished according to ASTM C 172. In this TRAMAN, only the procedure of sampling from a revolving drum truck mixer (TM) or agitator is discussed. If you should ever need to sample from a paving mixer, open-top truck mixer, or other type of equipment, be sure to refer to the most recent ASTM C 172.

Samples taken for the test specimens must be representative of the entire batch. This is accomplished by taking the samples at two or more regularly spaced intervals during discharge of the middle portion of the batch. Sample by repeatedly passing a scoop or pail through the entire discharge stream. Composite these samples into one sample for testing purposes. Be sure that the first and last portions of the composite sample are taken as quickly as possible, but never exceeding 15 min. If it is necessary to transport the samples away from the mixer to the place where the slump test is to be performed, combine the samples and remix them with a shovel to ensure uniformity.

Testing Procedures

Perform the slump test according to ASTM C 143. Be sure to start the test within 5 min after obtaining the final portion of the composite sample. In performing the test, first dampen the slump cone and place it on a flat, moist, nonabsorbent, rigid surface. From the composite sample obtained and while standing on the two foot pieces of the cone, fill the cone in three layers, each approximately one third of the volume of the cone. In placing each scoopful of concrete, rotate the scoop around the top edge of the cone as the concrete slides from it to ensure even distribution of concrete within the mold.

Rod each layer with 25 strokes of the tamping rod (using the rounded end), and uniformly distribute the strokes over the entire cross section of each layer. Rod the bottom layer throughout its depth. Rod the second layer and the top layer each throughout its depth so that the strokes just penetrate into the underlying layer. In filling and rodding the top layer, heap the concrete above the mold before the rodding is started. If the rodding results

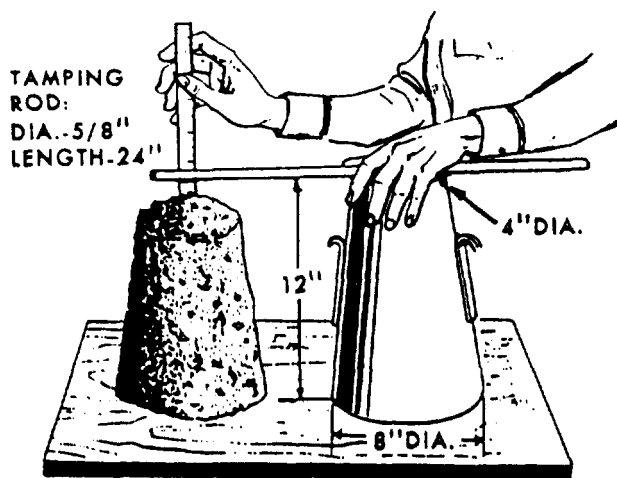


Figure 15-41. Measurement of slump.

in subsidence of the concrete below the top edge of the cone, add additional concrete to keep an excess of concrete above the top of the cone at all times. After the top layer has been rodded, strike the surface of the concrete off flush by means of a screeding and rolling motion of the tamping rod. Immediately remove the slump cone from the sample by carefully and steadily lifting it straight up at the rate of 5 ± 2 sec for the height of the cone. Place the cone next to the test specimen. At this point, the entire test from the start of filling the cone to completing the removal of the cone should not exceed $2 \frac{1}{2}$ min.

In measuring the slump, first place the tamping rod across the top of the cone so that it extends over the test specimen as shown in figure 15-41. Next, measure the vertical distance from the bottom of the rod to the average height of the subsided concrete specimen. This measurement is known as the SLUMP. If a decided falling away or shearing off of concrete from one side or portion of the specimen mass has occurred, disregard the slump measurement and make a new test on another portion of the sample. If two consecutive tests show a falling away or shearing off, the concrete probably lacks the necessary plasticity and cohesiveness for the slump test to be applicable.

After measuring and recording the slump, you have completed the slump test. As a supplementary procedure, however, tap the sides of the specimen gently with the tamping rod. The reaction of the concrete indicates its cohesiveness and

workability. A well proportioned, workable mix gradually slumps to lower elevations and retains its original identity. A poor mix crumbles, segregates, and falls apart.

If the slump test is performed for a trial batch during concrete mix design, then too little, or too much, slump indicates the need for a new trial batch with revised ingredient proportions. When the test is performed as a quality control measure for a construction project, the slump obtained by testing will be compared to the specified slump for the concrete used for that particular project. If too little, or too much, slump has been determined by the test, then the quality control inspector, or other appropriate authority, will determine whether to accept or reject the concrete.

PREPARATION OF CONCRETE SPECIMENS

Concrete specimens that are representative of a distinct batch of concrete must be sampled and analyzed for the purpose of quality control.

Cylinder Specimens

Tests are performed on concrete cylinder specimens to evaluate the compressive strength of the concrete. The standard cylindrical specimen is 6 in. in diameter by 12 in. long.

STANDARDS FOR CYLINDER MOLDS.—

Cylinder molds should be made of steel, cast iron, or other nonabsorbent material that does not react with concrete containing portland cement or other hydraulic cements. Molds should hold their dimensions and shapes under conditions of severe use. They should be able to hold, without leakage, the water poured into them. Before using the molds, coat them lightly with mineral oil or a suitable nonreactive form of release material.

FILLING CYLINDER MOLDS.— Place the molds on a level, rigid surface, free of vibration or other disturbances, at a place as near as possible to the location where they are to be stored for the first 24 hr.

Fill the molds with concrete specimens (taken as previously described for the slump test). The number of layers is determined by the mold size

Table 15-5.-Numbers of Layers Required for Specimens

Specimen Type and Size, as Depth, in. (mm)	Mode of Compaction	Number of Layers	Approximate Depth of Layer, in (mm)
Cylinders:			
12 (305)	rodding	3 equal	4 (100)
Over 12 (305)	rodding	as required	4 (100)
Beams:			
6 (125) to 8 (200)	rodding	2 equal	half depth of specimen
Over 8 (200)	rodding	3 or more	4 (100)

(table 15-5). As you fill a mold, rotate each scoopful of the concrete around the top edge of the mold as the concrete slides from it. This ensures a symmetrical concrete distribution within the mold.

Tamp each layer with the tamping rod, distributing the strokes uniformly over the cross section of the mold and penetrating the underlying layer. Tamp the bottom layer throughout its depth. The number of roddings is determined by the diameter of the cylinder. (See table 15-6.)

After tamping the top layer, strike off the surface with a trowel or rod so that the concrete fills the mold exactly. Do not add unrepresentative concrete to an underfilled mold. If voids are left by the tamping rod, tap the sides of the mold lightly with your open hand to close the voids. If desired, cap the top surface of freshly made cylinders with a thin layer of stiff portland cement paste, which you should then permit to harden and cure with the specimens. When finished, move the specimens to the storage place and leave them undisturbed for the initial curing period.

CURING AND STORING CYLINDERS.—

During the initial curing period of test specimens, be sure to take precautions to prevent the evaporation and loss of water in the specimens. Cover the specimens with a sheet of plastic. You may place wet burlap on top of the plastic to help retard evaporation, but be sure that it does not come in contact with the concrete surface. The exterior of cardboard molds must be protected against the absorption of water or molds may expand, allowing the specimens to be damaged. The test specimens now begin the initial curing period of 24 hr \pm 8 hr. Test specimens may be transported after the initial curing period, providing they

remain in the mold. Upon completion of the initial curing period, remove the specimens from the molds and place them immediately in a moist environment with water maintained on their surface at a temperature of 73.4°F \pm 3° (23°C \pm 1.7°). You can also obtain the required condition by immersing the specimens in saturated limewater or by storing them in a moist room or cabinet. Do not expose test specimens to a flow of running or dripping water.

CAPPING CYLINDERS.— The ends of compression-test specimens must be planed within 0.002 in. and within 0.5 degrees of being perpendicular to the axis of the cylinder.

Specimens formed in strong metal molds having accurately flat baseplates can be capped with neat cement at 2 to 4 hr after molding. A stiff paste of portland cement and water is made at the time the cylinder is molded so that the capping mixture will have shrunk before application. Any free water or laitance (layer of fine particles on the surface) is removed from the end of the specimen. The paste is applied to the top of the concrete and worked with a flat plate until it is smooth and level with the top of the mold.

Hardened concrete specimens may be ground to place ends or capped with a material having greater compressive strength than the concrete. Prepared mixtures of sulfur and granular materials, special high-strength gypsum plasters, and neat high-early strength cement are satisfactory capping materials (ordinary low-strength plaster of paris, compressible rubber, or fibrous materials are not suitable for caps). You should apply these materials in a plastic state and finish them to the desired plane surface by applying glass or metal

Table 15-6.-Number of Roddings to be Used in Molding Cylinder Specimens

Diameter of Cylinder, in. (mm)	Number of Strokes/Layer
6 (152)	25
8 (200)	50
10 (250)	75

plates and squeezing out excess material to provide a cap that is as thin as possible. Sulfur caps may be applied in time to harden for at least 2 hr before testing. Plaster caps cannot be stored over 4 hr in a moist room. Neat cement caps must be aged 6 days or more in a moist room (2 days when Type II cement is used). During capping, protect moist, cured specimens against drying by covering them with wet burlap.

Beam Specimens

Tests are performed on concrete beam specimens to evaluate the flexural strength of the concrete. The standard beam specimen is 6 in. by 6 in. by 21 in. (152 mm by 152 mm by 532 mm) for concrete in which the maximum size of the coarse aggregate is 2 in. (50 mm). When the maximum size of the coarse aggregate exceeds 2 in. (50 mm), the smaller cross-sectional dimension is to be increased to at least three times the nominal maximum size of the coarse aggregate. All beam specimens prepared in the field are to be at least 6 in. wide and 6 in. deep unless required otherwise by project specifications.

STANDARDS FOR BEAM MOLDS.— The beam molds are to be smooth on all interior surfaces and free from warpage. The molds are to produce specimens that do not exceed the required cross-sectional dimensions by 1/8 in. The length of the specimens is not to be more than 1/16 in. shorter than the specified length, but it may exceed that length.

RODDING.— Place the concrete in the mold in the required number of layers. (See table 15-5.) Rod the bottom layer throughout, distributing the strokes uniformly over the cross section of the mold. When rodding the upper layers, allow the rod to penetrate the previous layer 1/2 in., providing the previous layer is 4 in. or less and 1 in. if the previous layer is greater than 4 in. The number of strokes' per layer is one for each 2 in.² (13 cm²) of the top surface area of the specimen. After each layer is rodded, spade the concrete with a trowel along the sides of the mold to help in the removal of surface voids. Strike off the top surface with a straightedge, and finish it with a wooden float.

CURING.— YOU should cure the beam specimens in the same manner as the cylinder specimens with the following exceptions: (1) extend the initial curing period to 48 hr \pm 4 hr and (2) do not allow the surface of the beam specimen to become dry between the time of removal from curing and the completion of testing.

When transporting specimens from the field to the laboratory, be sure they are sufficiently cushioned to protect them from damage by jarring. Additional measures are required to prevent damage by freezing temperatures and moisture loss. You can prevent moisture loss by covering the specimens with plastic or surrounding them by wet sand or wet sawdust.

